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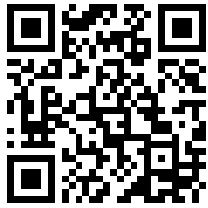

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A SURVEY OF RESEARCH PROBLEMS IN GEOPHYSICS

Prepared by Chairmen of Sections of the
American Geophysical Union

Published in the *Proceedings of the National Academy of Sciences*,
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A SURVEY OF RESEARCH PROBLEMS IN GEOPHYSICS*

PREPARED BY CHAIRMEN OF SECTIONS OF THE AMERICAN GEOPHYSICAL UNION

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These papers were presented at the first annual meeting of the American Geophysical Union, by the chairmen of the several sections of the Union. The meeting was held at the National Research Council in Washington, D. C., on April 23, 1920. The American Geophysical Union is also the Committee on Geophysics of the National Research Council and is the National Committee for the United States of the International Geodetic and Geophysical Union.

PRESENT STATUS OF GEODESY AND SOME OF THE PROBLEMS OF THIS BRANCH OF GEOPHYSICS

BY WILLIAM BOWIE

Geodesy is one of the oldest of the geophysical sciences. Originally it embraced only a limited field, consisting of the determination of the shape of the earth and its size and the means by which this was done. But now the subject of geodesy is very closely allied with other matters and there are few geophysical questions that do not, either directly or indirectly, concern the geodesist in the solution of his problems.

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Almost every country of the world that pretends to any standing has organized a service for the purpose of carrying on what are called geodetic surveys. As a matter of fact, any survey of the land in which the shape and size of the earth are taken into consideration can be called geodetic; thus, the hydrographic surveys along the coast made for a sailing chart are really geodetic surveys and, similarly, a topographic survey of a large area may be considered to be a geodetic survey; but what I have in mind in speaking of geodetic surveys, are triangulation, base measurements, precise leveling, etc.

By means of base measurements and triangulation, the geographic positions of places are determined which are of immense value in the permanent establishment of boundary lines between nations and political sub-divisions of a nation, for the control of various classes of surveys and maps, and for other engineering purposes.

Practically the whole of Europe has been covered by a system of points whose latitudes and longitudes have been determined by triangulation. This is also the case in Japan and in India. Australia, portions of Africa, and some of the countries of Central and South America have made good starts towards extending triangulation over their areas. In the United States excellent progress has been made in this work. There is triangulation around the entire border and there are many arcs in the interior of the country from which triangulation of precise or lower grades may be extended into every area in which detailed surveying and mapping operations are to be carried on.

It will be of interest to outline briefly the methods for carrying on triangulation or trigonometric surveys.

In the first place a spheroid of reference must be adopted which will approximate the actual shape and size of the earth. Then there must be an initial point whose astronomic latitude and longitude have been observed. Next is needed the azimuth or true bearing of a line of which the station occupied forms one end. After these data are available it is necessary to measure with extreme accuracy the distance between two intervisible points on the earth's surface to serve as a base. After the length of the base is known, additional stations are selected with a view to forming triangles by lines which are clear of obstructions and thus intervisible between their ends. It is, of course, a well known mathematical principle that when a side and the angles of a triangle are known, the other sides can be computed. When these sides have been computed from the base, either one of them can be used as the base for a new triangle. In a similar manner we may extend the computations through a long chain of triangles extending in some cases hundreds of miles across a country.

When the base has been measured and the angles observed and the computations of the triangles have given the lengths of the sides of the triangles, then computations can be made which will give the latitude and

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longitude of each point and the bearing of each line based on the data for the initial point, at which the astronomic latitude and longitude were observed and the true bearing determined of one line of the triangulation.

This is the simplest case of a geodetic survey where the whole net work depends on some initial astronomic station.

In practice, we have a much more complicated situation. Geodetic surveys have been started from many widely separated astronomic stations and the triangulation based on each has been finally extended until it meets the triangulation nets based on other astronomic stations. When this has been done, it is always found that the geographic positions computed from one astronomic station will differ from the geographic positions of the same points computed from other astronomic stations. We have a very striking example of this on the island of Porto Rico. The astronomic latitude was determined at Ponce, on the southern coast, and at San Juan on the northern coast of the island. The distance across the island, in a north and south direction, between these stations, is approximately thirty miles. The distance between the two stations, as computed from their observed astronomic positions, differs by about one mile from the distance between the two as determined by triangulation. The triangulation distance is correct within ten feet. The cause of this difference in distance as determined by the two methods is the attraction of the mountain mass, forming the Island of Porto Rico, on the plumb line to which the astronomic observations are referred. To the northward of Porto Rico are the deepest parts of the Atlantic Ocean and just to the southward of the island is a vast depth in the Caribbean sea. It can be readily seen that the effect of this distribution of mass in the oceans and in the island and its base is to draw the plumb line towards the centre of the island. This would throw the zenith on the south shore too far to the south and the zenith at the north shore station too far north. The plumb lines projected against the celestial sphere would therefore include a greater arc than they would under normal conditions. This angle is actually about 56 seconds of arc greater than normal.

In carrying on a geodetic survey, as described above, it is necessary to know accurately the elevations of the base lines and triangulation stations above the so-called plane of reference which is mean sea level. Each line that is determined by the triangulation is referred to sea level, that is, the computed distance between any two stations is the distance, along the geoid or sea level surface, between the points where the plumb lines at the two stations pierce this surface. Accurate elevations are also needed in many phases of surveying, in mapping, and in other engineering operations. They are also essential in many branches of science, notably in meteorology, geology, etc.

In order that elevations may have the maximum value to engineers it is necessary that they all be referred to the same, so-called, plane of

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reference. The one which has been almost universally adopted is mean sea level. It may be defined as the surface which would coincide with the surface of the oceans and their tide water branches if the tide producing forces should cease to act and there were no movements of the air and the barometric pressure were uniform. This surface can be determined at any point on the exposed coast by continuous tidal observations for approximately three years. The mean of the hourly readings of the tide record for such a period is practically free from error. If observations were made for a long period of years, it would be found that the average position of the surface of the ocean, for one three-year period, would agree very closely with the position of the surface for any other three-year period. The difference, if any, would be very minute.

It has been assumed by geodesists that, insofar as engineering work is concerned, mean sea level at each place along an open coast is in the same equipotential surface. This, of course, cannot be absolutely true because of different densities in the waters of the oceans, different barometric pressures, trade winds, and possibly other causes, but the deviation of mean sea level at one station from the equipotential surface containing mean sea level as determined at another station is so small as to be negligible in surveying, mapping, and other engineering work, and for practically all scientific purposes.

After the mean sea level surface has been determined, lines of very accurate spirit leveling are extended inland from the fundamental tidal stations. Each country of the world has done more or less of this work and in the United States we have tens of thousands of miles of this grade of leveling.

When a network of triangulation has been extended over a large area and astronomical latitudes, longitudes and azimuths have been observed at many of the stations, differences between the astronomic and geodetic positions of the stations are found. These differences are due to the deflection of the vertical, as was explained in the case of Porto Rico, and to the fact that the spheroid of reference used in computing the geographic positions of the triangulation stations differs from the actual figure of the earth. The former differences, namely, those due to deflections of the vertical, tend to be more or less accidental in character, while those due to an erroneous spheroid of reference are systematic.

After the triangulation and astronomic work have been done over an extensive area, the shape and size of the mean figure of the earth may be computed with a higher degree of accuracy, possibly, than the spheroid of reference on which the triangulation was originally based. For one hundred years or more we have made closer and closer approximations to the true figure of the earth, as the triangulations of the various nations have been extended. In the earlier of these determinations there was considerable uncertainty, owing to the deflection of the vertical caused by

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mountain masses and other topographic features. Some of the determinations of the figure of the earth were based on all of the observed geodetic data, that is, triangulation and connected astronomic stations, and other determinations were made to depend only on those data from which stations with large deflections of the vertical had been eliminated.

In the late fifties of the past century, Archdeacon John H. Pratt announced the theory that the geodetic data seemed to indicate that under mountain masses there were deficiencies of matter approximately equal in quantity to the masses that were above sea level. This theory was frequently commented on and studies were made to intepret certain geological features by means of it.

In 1889, Major C. E. Dutton, in an address before the Philosophical Society of Washington, entitled "On some of the greater problems of physical geology,"[1] applied the term "isostasy" to this theory of equal pressure, that the mountains are accompanied by deficiencies of mass under them and that there is an excess of matter under the oceans.

About fifteen years after Dutton gave prominence to this theory, Prof. John F. Hayford, at that time Chief of the Division of Geodesy of the United States Coast and Geodetic Survey, began investigations which showed rather conclusively that the material above sea level is counterbalanced to a marked degree by a deficiency in density of material in the column directly under the exposed material. This column, which is affected by this decreased density, was found by Hayford to extend to a depth of approximately 122 kilometers, if the compensation is assumed to be uniformly distributed. Hayford also found that the column extending approximately 122 kilometers below the bottom of the ocean has a density in excess of normal that will balance approximately the deficiency of matter in the mass of water directly above the column.

This condition of approximate equilibrium in the earth's material at a depth of approximately 122 kilometers was applied by Hayford in determining the figure of the earth from geodetic data in the United States. The results appear in his report published in 1909,[2] which gives dimensions for the earth that are believed to be of a higher order of accuracy than any previously arrived at. This is because the theory of isostasy was considered in this work. It is hoped that in the future the theory of isostasy can be considered in deriving a figure of the earth from all available triangulation data in the world.

In order that this figure of the earth may be computed it will be necessary to have some central office to guide the investigators of the several countries who may assist in the work. Undoubtedly this central office should be under the direction of the Division of Geodesy of the International Geodetic and Geophysical Union, although the central office itself might be located in a geodetic organization of any one of the countries adhering to the union.

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In North America great progress has been made in coördinating the geodetic work of the several countries. Some years ago, there was adopted for the triangulation net of the United States what was called the United States Standard Datum. This datum had its designation changed to North American Datum when, in 1913, it was adopted by Canada and Mexico. It is hoped that within a few years a continuous triangulation will be extended into Alaska from the United States and then that territory can also have its triangulation placed on the same datum as the rest of the continent.

A datum may be defined as the adopted latitude and longitude of some station of the triangulation and the azimuth of a line of the triangulation radiating from that station. It also includes the dimensions of the reference spheroid, on which the triangulation is computed.

The advantages of a single datum are, first, that it makes it possible to compute the figure of the earth with greater accuracy and, second, that it avoids the confusion existing in the maps at the frontier of any country when the adjoining countries base their surveys and maps on different datums. Whenever the datums are different, boundary monuments have different geographic positions on the maps of the two countries and there are overlaps, gaps, and offsets in the maps, which frequently result in controversies over the boundary line.

One of the greatest needs in Europe to-day, from a geodetic standpoint, is the adoption of one datum for the whole of its area. This would involve a tremendous amount of revision of the computation and adjustment of the triangulation nets of the several countries, but the resulting benefits would far offset the cost of the work.

Trigonometric leveling is a branch of geodetic work which, though important, is not as much so as triangulation and precise leveling. It is employed in determining the elevations of the triangulation stations in order that the lines observed may be corrected to what they would be if the observations were made at sea level. Theoretically, trigonometric leveling should furnish data from which to compute the shape of the geoid, but this is impracticable owing to our inability to know the exact value of the atmospheric refraction at the instant of observation. Trigonometric leveling is of value in determining the elevations of mountain peaks used as stations or those outside of the main scheme of the triangulation. It is by this method that the elevations of Pikes Peak, Mt. Everest, Mt. McKinley and many others, have been determined.

A branch of geodetic work which has been receiving great attention during the past decade or more is the determination of the intensity of gravity. For a number of years observations were made using reversible pendulums in order to determine the absolute value of gravity. Following this, observations were made with what were called invariable

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pendulums approximately one meter in length, to get the relative value of gravity or the difference in gravity between two places, one of which was the base station. These results were not particularly satisfactory because the pendulums were swung in the air with rather poor temperature control and the effect of the flexure of the support due to the swinging pendulum was not considered, or, if it was, was not accurately determined.

About 1885, Von Sterneck devised an apparatus which consisted of a quarter-meter pendulum of the invariable type, swung in a case from which the air could be almost entirely exhausted. With this apparatus, the difference in gravity between two stations could be determined with a high degree of precision. There have been modifications of the Von Sterneck pendulums, but only in minor features, the general principle of the apparatus remaining unchanged until this time.

With the short pendulums of the Von Sterneck type it was possible to establish a station in a very short time and at a very low cost. The result has been a great stimulation of effort in this branch of geodetic work. Most of the countries of the world carrying on geodetic operations have adopted this type of pendulum and many stations have been established.

In 1908 there were 47 modern gravity stations in the United States, while to-day there are 276 such stations.

Gravity determinations have a number of uses; one is to furnish a formula by which the value of gravity can be computed for any latitude for use in the physical and chemical sciences; another, to furnish data by which the shape of the earth may be determined; and another, to furnish data for making studies of the theory of isostasy or the deviation from normal densities of matter in the outer portion of the earth.

As a result of the application of the theory of isostasy to the gravity determinations in the United States, the shape of the earth, or rather the amount of its flattening, has been determined by investigations made by the Coast and Geodetic Survey and published in 1917 as Special Publication No. 40 of that Bureau. The reciprocal of the flattening was found to be 297.4. This value is probably the most reliable one in existence to-day. There were also derived from this investigation new constants for the gravity formula for computing the value of gravity at any latitude. This formula was adopted by the U. S. Weather Bureau and by the Smithsonian Institution in the preparation of the latest edition of the Meteorological Tables. In that investigation was also determined the depth of compensation; that is the depth at and below which the materials of the earth are supposed to be in a state of equilibrium. This depth was found to be 96 kilometers, which agrees very closely with the value derived by Hayford in his determination of the figure of the earth at stations in mountainous regions only. It is necessarily true that a depth of compensation can be derived from data in elevated regions with greater certainty than where the land is low. The higher land is liable to be freer

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from constant or systematic deviation from normal conditions in the immediate vicinity of a station.

The gravity observations not only give a means of determining whether there are regional deviations from normal densities in the outer portion of the earth under the continents and oceans to cause equilibrium at the depth of compensation, approximately 96 kilometers, but they also afford an opportunity to detect abnormal densities in the materials of the earth which are close to the surface but below sea level. Recent investigations in the United States and in India show a decided relation between the value of gravity and the Cenozoic geologic formation. This formation is approximately 10% lighter than the material in the older geological formations. Pendulum observations may be a means of indicating the approximate depth to which the Cenozoic formation extends at any place.

Gravity observations also indicate a relation between the value of gravity and the Pre-Cambrian formation. In this formation the material is, in general, somewhat heavier than normal, and when a gravity station is established at or near Pre-Cambrian rocks the value of gravity is found in most cases to be greater than normal. It is not improbable that a knowledge of this relation between the Pre-Cambrain formation and the gravity anomaly may make it possible to discover crystalline rocks or others that are extra heavy which may be covered by materials of normal or lighter densities. If this proves to be the case, it may be possible to locate areas underlaid by dense rocks close to the surface of the ground, which may have an economic importance in connection with boring for oil. Much money has been lost by oil prospectors in drilling in regions which have been found by them to be underlaid by crystalline rocks.

It is seen that gravity determinations have much more than a purely geodetic value. The results obtained from them will undoubtedly have a very great effect on the science of geology.

There are geophysical problems that would be considerably cleared up if the value of the intensity of gravity over the oceans could be determined accurately. Such observations would make it possible to determine whether the outer portion of the earth under the ocean is in the same isostatic condition as has been found under the continents. It would seem probable that isostasy obtains to the same extent under the oceans as under the land, but it has not been possible to prove this in the absence of accurate gravimetric determinations on the ocean.

It is true that gravity observations have been made over the ocean, but the apparatus, in each case, lacked the necessary precision to give the value of gravity with a sufficiently high degree of accuracy. It is probable that improvements will be made in the apparatus for determining gravity at sea and when one has been perfected to such an extent that it will give results of adequate accuracy, a long step forward will have been made in geodesy.

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The theory of isostasy has some corroborative evidence in the form of a relation between the elevation of the ground and the density of the igneous rocks. Recently Dr. H. S. Washington delivered a paper at a meeting of the Geological Society of Washington in which he showed very conclusively that the higher the elevation at which igneous rocks are found, the smaller the density of such rocks. This tends to confirm the theory of isostasy which postulates the higher the land the less the density in the column under it, down to some indefinite depth called the depth of compensation, approximately 96 kilometers.

It is hoped that these studies by Dr. Washington may be continued by him and by others, for their results will undoubtedly be of great value to geophysicists in general and especially to geologists working in the subject of isostasy.

Another matter that is assuming importance in geodesy is the determination of earth tides. These were studied by the International Geodetic Association, a station having been established for this purpose in Europe some years ago. The apparatus used was of sufficient delicacy to show that there is an earth tide caused by the tide producing forces of the moon and sun, but it could not be considered that the results obtained were entirely satisfactory. This condition has been changed, as a result of the construction of an earth tide apparatus by Prof. A. A. Michelson, of the University of Chicago. This apparatus consists essentially of two tubes placed horizontally in the ground, one in a north and south and the other in an east and west direction. These tubes are partially filled with liquid and the tide producing forces cause an inclination of the liquid surfaces, producing the phenomena of tides. The actual amount of tilting of the surface of the liquid is determined by the interferometer method.

The differences between the tides, as observed in the horizontal tubes, and the theoretical tides that would be produced on the earth, if it were rigid, give the measure of the actual distortion of the earth itself. This apparatus of Prof. Michelson is considered to be entirely satisfactory and it is hoped that it may be used nationally and internationally in determining the value of the earth tides at different parts of the earth and under different geological conditions.

From the result of the earth tides, values can be deduced for some of the physical properties of the material of the earth, such as elasticity and viscosity, at different distances from the surface. A knowledge of these will be of great geophysical value.

Seismology is a geodetic subject in the sense that it throws light on the constitution of the interior of the earth and thus assists in investigations of the shape of the earth. As was said in the first part of this paper, geodesy originally had as its function the determination of the figure of the earth, but in order to ascertain why the figure of the earth is such as

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we find it, a knowledge of the physical characteristics of the material composing the earth is essential. Seismology in connection with the investigation of the earth tides should furnish much information regarding the physical properties of the material of the earth at various depths.

A subject that is of interest to many geophysicists as well as to astronomers is the variation of latitude which has been studied for a number of years by the International Geodetic Association. While certain parts of the variation have been found to follow certain laws of change there are still apparent irregularities not yet explained.

From investigations dating back to Euler's time it was at first supposed that the latitude variation, if found, would have a period of about ten months, this being on the supposition of a rigid earth. It is found that the principal part of the polar motion has a period of 14 months. From this fact it is inferred that the earth is not rigid, and from the numerical amount of the lengthening of the period we may draw inferences as to the elastic properties of the earth as a whole; these inferences agree in a general way with what has been found by investigations along other lines. We naturally expect the shifting of the pole to be accompanied by a shifting of the ocean waters responding to the change in the centrifugal force of rotation. This latitude-variation tide has already been studied to some extent without in any way exhausting the subject.

This problem of determining the variation of latitude at observatories is really an astronomic one, although it has a geodetic bearing. The figure of the earth, determined from triangulation and astronomic data, is affected though very slightly by this variation. When it was found desirable to carry on systematic observations on an international scale, there was no astronomic organization with sufficient funds to do the work. The problem was presented to the International Geodetic Association, which had a source of funds not available to the International Astronomic Society. The result was that the International Geodetic Association undertook the work and has carried it on continuously, even during the war, for twenty years or more. The work must not be discontinued nor should there be any break in the observations at the international stations in Italy, Japan and the United States.

Geodesists are interested in the science of volcanology or at least in certain phases of the work in that science which may throw light on the constitution of the material, with densities and temperatures, in the outer portion of the earth, and the cause of volcanic activity. It is believed that these data will supplement the information obtained from the several other lines of investigation such as gravity determinations, earth tides, seismology and variation of latitude.

There is another subject which is of particular importance to geophysicists and, I might say, of very great interest to geodesists. This is what may be called geo-mechanics. It would embrace an investigation to

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show the relation of forces to movements of material, the origin of forces, and their causes. It would really combine the subjects of isostasy, earth tides, variation of latitude, seismology, and certain phases of volcanology. The data collected in those branches of geophysics should be considered in connection with geology in order to interpret in the light of present knowledge the various movements that have taken place in the earth. Up to this time, it is believed that these data have not been given due consideration and weight in the study of the earth, its structure, forces, etc.

Some of the subjects that have been discussed above are only incidentally related to geodesy, but the results of investigations in them are certainly of great value and interest to geodesists and it is believed that there should be committees of the Section of Geodesy of the American Geophysical Union to consider these questions and be able to inform the members of the Section at any time as to the progress made in these branches of geophysics. There are several of the subjects which have sections of their own, for instance, those of Seismology and of Volcanology.

The Geodetic Section of the American Geophysical Union will not attempt, nor does it desire, to pre-empt any field of geophysics nor will it encroach on the rights and privileges of any other organization. It will simply attempt to keep informed of what is going on in the various fields of geophysics which are of interest to geodesists and it hopes that it may from time to time give some assistance to other organizations in suggesting problems or lines of research. On the other hand, it stands ready to receive suggestions and help from any other organization dealing in any branch of geophysics.

[1] *Bulletin of the Phila. Soc. of Washington*, 11 (51–64).

[2] Supplemental Investigations of the Figure of the Earth and Isostasy from Measurements in the United States.

THE PROBLEMS OF SEISMOLOGY

By Harry Fielding Reid

Although earthquakes have received sporadic attention for some time in the past, their systematic study may almost be said to have begun with Mallet about the middle of the last century; and it was only towards the end of the century that instruments delicate enough to register distinct shocks were developed, making it possible to gain some knowledge of the characteristics of earthquake vibrations and the velocities with which they are propagated through the earth. But, notwithstanding the shortness of the time during which these studies have been in progress, the science has been well outlined and first approximations to the solutions of many of its problems have been obtained. The time has now arrived

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for more concentrated and still more systematic attacks, from which important results may be confidently expected.

We can summarize the general state of our knowledge of earthquakes as follows:

Nearly all earthquakes are due to the sudden fracture of the rock of the earth's crust, which has been strained by slow earth movements beyond its strength. Strong vibrations are set up at the fractured surface at the time of the fracture, just as vibrations are set up whenever any solid is broken. The earth consists of solid material, which is necessarily elastic, and therefore these vibrations are transmitted through it as elastic waves. There are two kinds of elastic waves: normal waves, where the movement is in the direction of propagation, and transverse waves, where the movement is at right angles to the direction of propagation. These two kinds of vibration advance with different velocities. Their velocities near the earth's surface are about 7 and 4 kms. per second, respectively; but the deeper they penetrate below the surface the faster they go. Therefore, from the characteristics of elastic waves their paths are curved and concave upwards. These important results have been obtained by a study of the time necessary for the two types of waves to pass from the place of their origin to stations at different distances where delicate instruments are installed, which record the time of their arrival. It may seem remarkable that the paths followed by the rays and the velocity in different parts of the paths could be determined merely from the time required to arrive at a number of places on the earth's surface; but, by the help of some rather abstruse mathematics, it can be done. One interesting conclusion which can be drawn from the passage of the transverse waves through the body of the earth is that the earth is a solid and not a liquid sphere; for transverse waves can be transmitted only by solid substances.

There are other waves which are transmitted along the surface of the earth; they must be started in some way when the body waves, mentioned above, arrive at the surface, but we do not know just how near the origin their starting place is.

In many instances submarine earthquakes give rise to great water waves, which have been known to travel from one side of the Pacific Ocean to the other. It has been the general belief that the first indication of these waves along a coast is marked by the withdrawal of the water; and the great elevated wave follows. Although this order is certainly frequent, it is not general, and in many cases the elevated wave is first to appear.

This is a very summary sketch of what has been learned about earthquakes in the comparatively short time that they have been systematically studied; but it will serve as a basis from which to point out the problems which are now pressing for solution.

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For our present purposes we can classify seismological problems into:

A. World-wide.
B. Regional.
C. Theoretical and Auxiliary.

A. World-wide Problems

The noted seismologist, the late John Milne, has estimated that fifty or sixty earthquakes, strong enough to be recorded on seismographs in all parts of the world, occur every year. The study and comparison of the seismograms made at these scattered observatories requires international coöperation, and this will be provided for by the new International Geodetic and Geophysical Union.

The problems facing us are numerous, but perhaps the most important is the accurate determination of the time of the earthquake waves to pass from their origin to points on the earth's surface at various distances from it. We already have a fair knowledge of these times, but need more accurate determinations. This information serves two main purposes: it enables us to determine the origins of earthquakes when they occur in inaccessible regions or under the sea, and thus gives us information of the regions of seismic and therefore of geologic activity; and it enables us to trace out the paths and the velocity of the earthquake waves through the earth, thus throwing light on the physical condition of the earth's interior.

The records of earthquakes at distances of more than about 110° from the origin have proved very unsatisfactory. It is still uncertain whether this is due to the imperfections of our observations or, as Oldham thinks, to the existence of a central core in the earth having different physical properties from the material surrounding it, which materially changes the direction of propagation of the seismic vibrations passing through it, and may even damp some of them out entirely. This very interesting suggestion deserves to be tested.

Professor Wiechert and his collaborators have announced the existence of several shells in the earth where the velocity of propagation of the waves suddenly changes. These results are based on the form of the transmission curve; but, unfortunately, this form is not known with sufficient accuracy to justify the conclusions.

Do earthquake waves travel under the continents and the oceans at a different rate? We can say that the difference is certainly small, but we cannot say that there is no difference. These are some of the problems dependent for their solution on increased accuracy of the transmission curve.

The comprehensive work of the Count de Montessus de Ballore on the distribution of earthquake centers on the earth, has shown that 95% of all earthquakes on land occur in two broad zones, one surrounding the

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Pacific Ocean and one passing through the West Indies, the Mediterranean, and the East Indies. These zones are the regions where sediments were accumulated in middle geologic times, known as the Mesozoic Age; after consolidation into rock they have been elevated and in places they now form the highest mountain ranges in the world. De Montessus de Ballore's great work need not be repeated; what is now needed is a detailed study of the distribution of earthquake origins in special regions, and this comes under our third class.

But the distribution of earthquake centers under the seas is still in an embryonic state. A good beginning in the study of this problem has been made by Rudolph, but far more data are needed and they can only be supplied by the records of many widely-spread observatories.

Much study has been given to periodic variations in earthquake activity and its possible relation to variations of latitude, to the positions of the sun and moon, to the seasons, etc. Although this line of investigation has not yielded satisfactory conclusions and, in the opinion of some competent seismologists, is not destined to be fruitful, others believe in its possibilities. If it is to be pursued successfully it is important that a good catalogue of submarine earthquakes be added to the catalogue of those occurring on land. There are a sufficient number of seismological observatories in the United States to supply the data required from this country towards the solution of these world-wide problems, though perhaps a new station somewhere in Texas and another in Montana or Idaho might be of advantage. The effort should be to improve the stations already functioning rather than to increase their number. The examination of many earthquake records has convinced me that not a few observatories are provided with poor clocks, or that insufficient care is given to them. Better time-keeping will greatly increase the accuracy of the records. Some of the best observatories should have a more complete equipment. They should have seismographs of high magnifying powers to catch the very feeble movements, and seismographs of low magnifying power, that the characteristics of the stronger movements may not be lost by too wide a range of the recording point. They should have instruments to record vertical motion, a component that has received far too little attention. I believe there are but two vertical component instruments in this country.

When we consider the important area covered by the Pacific Ocean, we find that there are stations in Japan, Formosa, the Philippines, Australia, New Zealand, Chile, Panama, Mexico, California, and Sitka; and on the islands of Oahu, H. I., Guam, and Samoa. The last station was a branch of the Physical Institute of Göttingen and should not be allowed to fall into desuetude. A station on one of the Aleutian islands would also gather valuable information.

Knott has shown that the greater part of the energy of an earthquake

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comes to the earth's surface within a short distance of the epicenter, and 95% within a distance of 90°. When we consider that the earthquake originates at a fault and that the mass movement there may be horizontal, inclined, or vertical, we realize that the energy sent out in different azimuths, and indeed at different vertical angles, may be dependent on the direction of the fault and of the mass movement, but no information has yet been obtained on this subject.

B. Regional Problems

The accurate surveys made by the United States Coast and Geodetic Survey of parts of California before and after the earthquake of 1906, made it very plain that slow movements of the earth's crust during some scores of years finally brought about a rupture of the rock along the San Andreas Fault, and that the two sides of the fault flung back in opposite directions under the elastic forces set up in the rock by those movements. But no information was gained regarding small ruptures taking place preliminary to the main break, nor regarding the location of the many sudden movements after the shock, causing what are known as aftershocks. A methodical study of a limited area where small shocks are frequent and strong shocks are occasional would throw much light on the sequence of events leading up to the rupture producing a strong shock, on the way in which the rupture is gradually enlarged, on the depth to which it extends, and on the order according to which quiet is gradually restored. It seems not impossible that the location of the preliminary shocks might serve to block out the fault along which a rupture was about to take place. Davison's study of the shocks preliminary to the severe Mino-Owari earthquake of Japan in 1891, seems to encourage this idea. But it is important that the actual origins of the shocks should be determined; it is insufficient merely to list the places where the shocks were felt; this last method has led to serious error in the past. By placing simple monuments in properly selected positions and fixing their relative positions and heights from time to time by careful surveys, the slow movements of the crust and the relation of these movements to earthquakes could be discovered. Information could also be gained regarding the relation of the geological structure and the physiography of a region to its seismic activity.

The velocity of transmission of earthquake vibrations in the immediate vicinity of the origin and near the earth's surface, can only be satisfactorily studied by placing a number of seismographs at comparatively short distances apart, and not far from the origin of the shock. A good determination of this velocity would add precision to many seismological problems.

There are many other problems that come in this class. Microseisms, small vibrations continuing for hours, frequently interfere with the satis-

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factory recording of earthquakes. The origin of these vibrations is not understood. They may be connected with meteorological conditions. The actual movements of the ground, velocity and direction of propagation of the microseisms should all be studied and compared with the direction of the wind and the direction of the barometric gradient. The concentration of a number of similar seismographs in a limited area would furnish the proper conditions for the solution of this problem.

The influence of the foundation, rock or alluvium, upon the intensity of the vibrations; the relative intensity of the movement in a mine and above ground, due to local or to distant earthquakes, etc., are examples of regional problems before us.

The study of the actual effects of strong earthquakes usually follows somewhat different methods. It requires the examination of the region where the shock has left visible marks by a competent seismologist. The experiences of persons present must be collected; the damage to buildings and other structures noted; and the relation of the earthquake to the geology of the region determined. The slow surface waves in alluvium, sometimes called "gravity" waves, are still a great enigma, and require special attention. A few portable seismographs should be available and should be placed in suitable positions to record and locate the aftershocks. If in addition to these field studies, instrumental records before, during, and after the strong shock should have been made the two kinds of information collected would not only supplement but would add greatly to the value of each other.

C. Theoretical and Auxiliary Problems

The results obtained by world-wide and by regional studies must be woven together into a unified whole and the fundamental laws of the sciences deduced. This kind of work is only done occasionally, and then by individuals who have developed an unusual insight into their science. There are many problems, however, which do not come either under the world-wide or the regional problems, which are important either in helping the solution of these problems, or in elucidating the meaning of the data collected. For instance, the theoretical and experimental study of seismographs is of great importance. It looks to a better interpretation of the seismograms, and to improvements of the instruments, or the development of new forms of instruments. This is work to be done in the study or in the laboratory, but should be in close touch with observations in the field. In particular, we need an instrument that will give a correct record in the shaken area of a strong earthquake.

Then there are many problems, such as the actual genesis of the vibrations, the transmission of body and surface waves, the changes in the character of the waves on reflection, the reasons for differences in the instrumental records of different earthquakes, the peculiarities of earthquake sea-waves, etc.

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Although the various seismological problems have been, for convenience, classified into three groups, it must not be inferred that they are sharply defined and distinct; each group will contribute to the problems of the others. Instruments that are primarily intended for world-wide problems will yield information bearing on local problems in their neighborhood; and instruments meant for local problems will also record the world-shaking earthquakes.

Relations to Other Sections of Geophysical Science

For convenience we divide science into branches, influenced largely by differences in the methods used. But nature knows no such dividing lines; and we find that many problems can be solved only by the cooperation of several branches. This is especially true of the geophysical sciences. The special section of seismology looks to all the other sections for help; to geodesy to determine the slow earth movements, horizontal or vertical, that lead up to earthquakes, and the sudden movements that take place at the time of the shock; to meteorology to tell us the atmospheric conditions when microseisms are prevalent; to physical oceanography for information about the deeps of the oceans, along whose borders submarine shocks are common.

The independence of earthquakes and volcanoes has been strongly emphasized during the last thirty years, because nearly all the strong earthquakes were unaccompanied by volcanic phenomena of any kind; and, on the other hand, the great volcanic outbursts, such as Krakatoa in 1883 and Mt. Pelée in 1902, caused only insignificant earth tremors. These facts cannot be contraverted; and still we must not forget that the volcanic belts lie in or near the great earthquake zones; and there may be some common cause of both classes of phenomena.

The influence of earthquakes on suspended magnets may be assigned, with much confidence, merely to the mechanical vibrations. But may not the altered state of strain, in the neighborhood of the generating fault, change the magnetic condition of the rock there if the rock contains magnetic minerals, so that the general magnetic field might be modified? Or may not the passage of violent earthquake waves through magnetic rock alter its magnetization, especially if that magnetization was assumed at some time when the earth's field was different from what it now is?

Seismology does not ask without giving. It can contribute its conclusions to the other branches of science and help them in the solution of their problems.

THE STATUS AND PROBLEMS OF METEOROLOGY

By C. F. Marvin

Meteorology is one of those sciences which developed on the side of practical application for the welfare of mankind to a far greater extent

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than the development on the scientific or pure theory side of the problem. As a result, meteorologists responsible for the practical applications to human welfare are at a distinct disadvantage on account of the imperfect and incomplete theoretical development of the science.

The United States was distinctly the pioneer among all nations in officially and formally creating a meteorological service. This was done by a joint resolution of Congress in 1870, which provided that advices, warnings and forecasts concerning future weather conditions should be prepared and issued for the benefit of agriculture commerce and navigation.

The greatest achievement of the Weather Bureau is doubtless that of creating the present organization of a service of applied meteorology from the nucleus resulting from this early legislation.

Taking the U. S. Weather Bureau as a prominent example of a well-developed, thoroughly organized agency for the application of the principles of meteorology to the welfare of man, it seems appropriate to outline below, in the briefest possible manner, the principal activities and subdivisions through which this public service is rendered.

THE WEATHER BUREAU

A Daily Service of the Science of Meteorology Applied to Human Welfare. —When Congress created the Weather Service in 1870, the primary object was to benefit and protect navigation on the Great Lakes and Atlantic coast by advance warnings of dangerous storms. Later the issue of flood warnings was added to its duties. To-day there is scarcely any important industry or activity of the nation which is not to a greater or less extent influenced by weather conditions, and therefore needs the advices, information and economic benefits which flow from the full and efficient administration of all its duties.

These benefits are of great variety and the information, advices and warnings of the Weather Bureau serve the immediate needs of practically every interest and industry of the nation. Great atmospheric disturbances visit with relative frequency one section of the country or another. Violent storms, cold waves, frosts, freezes, hurricanes, floods, heavy snows, and the like, repeatedly cause destruction of property, such as shipping on the Great Lakes and coastal waters of the nation, and, in recent times, the lives and property engaged in aerial navigation. Crops and farms in flooded districts are laid waste. Lambs, livestock, and meat animals in the stock ranges of the west are killed by blizzards and cold waves. Orchard crops, truck gardens, and vineyards everywhere are damaged by frosts and freezes. By forecasts and warnings, issued and disseminated well in advance, great economic benefits and saving accrue to the nation through the precautionary measures which can be taken on timely ad-

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vices to minimize or ward off injuries which otherwise inevitably attend the great atmospheric phenomena mentioned.

The following comprise the principal items of service:

SUMMARY OF WEATHER BUREAU ACTIVITIES

1. Weather Forecasts and Warnings

Weather forecasts and warnings are based upon simultaneous observations of local weather conditions taken daily at 8 a.m. and 8 p.m., 75th Meridian time, at about 200 regular observing stations scattered throughout the United States, and upon similar reports received daily from points in the West Indies, Central America, Hawaiian Islands, Alaska, Canada, Bermuda, and a few other parts of the Northern Hemisphere. The reports are received by telegraph, charted, and the forecasts and warnings deduced therefrom are issued from district centres located at Washington, D. C., Chicago, Ill., New Orleans, La., Denver, Colo., and San Francisco, Calif. The forecasts and warnings are of varying classes as follows:

(*a*) *Daily Forecasts and Weather Information.*—These forecasts are issued twice daily in the a.m. and p.m. and are telegraphed to about 1,600 principal distributing points and thence they are further disseminated by telegraph, telephone, radio and mail to several thousand communities. They are furnished also to the press association and newspapers and are published by practically every daily newspaper in the United States, thus reaching all sections and every class of people. The weather observations on which the forecasts are based are printed in map and bulletin form and mailed or delivered to commercial, marine, agricultural, industrial organizations, educational institutions, etc.

These maps and bulletins are prepared, printed and distributed within three hours after the observations are taken.

The manifold uses to which the daily weather forecasts and weather information are applied are impracticable of enumeration as the life and activity of the whole population is more or less affected by the weather and receives more or less benefit therefrom.

(*b*) *Weekly Forecasts.*—Forecasts are made each Saturday for the six days beginning with the ensuing Monday. These forecasts are made separately for nine districts covering the entire United States, and necessarily are couched in general terms. They are immediately telegraphed to certain designated centres whence they are further disseminated by telegraph, telephone, and mail, and are published in Sunday and Monday newspapers following the day of issue.

These forecasts are intended more particularly for the agricultural interests, as a guide to their activities during the growing season; and the Weather Bureau is in receipt of many communications testifying to their great value.

(*c*) *Shippers' Forecasts.*—Forecasts of temperature expected within the following 24 to 36 hours that will be injurious to perishable products in shipment are made by officials in charge of the stations located in large commercial centres. They are issued only when temperatures of 32 degrees or lower, or 90 degrees or above, are expected.

Special distribution of these forecasts is made to railroads and shippers of perishable products. Shipments are to a large degree regulated by these forecasts. The saving affected thereby is enormous.

(*d*) *Storm and Hurricane Warnings.*—This service consists of the issuance to shipping interests on the Atlantic, Pacific and Gulf coasts and in the waters adjacent thereto and on the Great Lakes, of warnings of the approach of storms dangerous to shipping, and to the coasts of the South Atlantic and Gulf States and adjacent regions of the approach of hurricanes. These warnings are disseminated by means of flags by day and lanterns by night, displayed at about 425 ports. In addition, the warnings are tele-

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phoned and telegraphed to practically all maritime interests and broadcasted by wireless to ships in the threatened regions. So nearly perfect has this service become that scarcely a storm of marked danger has occurred for years of which ample warnings have not been issued from 12 to 24 hours in advance.

The sailings of the immense number of vessels engaged in our ocean and lake traffic are largely determined by them. Warnings displayed for a single hurricane are known to have detained in port on our Atlantic coast vessels valued, including their cargoes, at over $30,000,000. Fewer dangerous storms than usual occurred during 1919. However, one unusually severe one occurred on the Lakes in November, accompanied by wind velocities of over 80 miles an hour. Owing to the ample advance warnings not a single marine casualty was reported. Only one tropical hurricane occurred, namely, that of September 6–14, 1919, that passed over southern Florida, traversed the Gulf of Mexico and struck the coast of Texas near Corpus Christi. It was attended by large losses in life and property that were inevitable, but the saving to ships and other property as well as lives was incalculable because of the warnings that were distributed well in advance of the storm. This hurricane was of extraordinary intensity and the efficiency of the warnings was so complete that the portion of the Gulf of Mexico which it traversed was practically cleared of shipping; otherwise many ships valued at millions of dollars would have been caught in the storm. Few, if any, ships caught within the storm centre could have survived. This efficiency of service added to the difficulties of the forecaster, because he was unable to secure wireless reports from the region of the storm centre which were so necessary for an accurate determination of the hurricane's direction and progress.

(*e*) *Cold Wave Warnings.*—These are warnings of sudden and destructive temperature changes that frequently sweep across the country during the winter season. They are issued from 24 to 36 hours in advance and are disseminated throughout the threatened regions by means of flag displays, by telegraph, telephone and mail.

The uses made of these warnings are manifold. They are especially valuable to railroads in the making up of trains and the maintenance of schedules, to shippers of perishable goods, cattle growers, and innumerable business organizations. The warnings issued in a previous year for a single cold wave of exceptional severity and extent resulted, according to reliable reports, in a saving of over three and a half million dollars. No unusually severe cold waves occurred during 1919, although warnings were issued on about 30 different occasions for moderate cold waves.

(*f*) *Frost Warnings for Truckers, Tobacco, Cranberry and Sugar Growers.*—These warnings are issued whenever conditions indicate the occurrence of damaging frosts. The growers take advantage of these warnings to protect their crops by the various means in vogue. In many instances the growers are dependent upon the Weather Bureau for these warnings as without them their industries would be too hazardous to be profitable. This is especially true of early trucking in the South Atlantic and Gulf States. During the year 1919 rather fewer instances than usual of weather conditions necessitating these warnings occurred; but during the year previous it is of record that warnings of a damaging freeze saved nearly one-third of the entire sugar crop in Texas and Louisiana by enabling the growers to windrow the standing cane.

Special frost warnings are sent to all parts of the tobacco-growing section in Wisconsin and Connecticut. Information of current weather conditions during the growing season is also supplied to the other large producing areas.

Frost warnings are sent to the principal cranberry-growing sections of the country, which enable growers to protect their crops by flooding or other protective means. They are indispensable to this industry.

(*g*) *Fire Weather Warnings.*—These warnings are issued whenever conditions are favorable for hot, dry winds, which are favorable to the inception and spread of fires

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in the National and other forested regions. They are distributed principally to Forest Service officials and others charged with forest protection.

The warnings aid in the protection of the forests by enabling crews and apparatus to be ready for action. Numerous testimonials of their value have been received. several in the form of resolutions passed at the conventions of Forestry Associations, urging appropriations.

(*h*) *Forecasts and Warnings for Stock Growers.*—This service covers the western and northwestern portions of the country and consists of warnings of cold waves, high winds and heavy snows. These warnings enable stock men to make proper provision for the protection of stock exposed on the ranges. They are of especial value to sheep men during the shearing and lambing periods as heavy losses sometimes occur when proper protection has not been provided, sometimes as much as 50 per cent of individual flocks. In the States of Washington, Oregon, and Idaho alone there are two million sheep valued at $12,000,000, exposed to the weather and the sheep men depend largely on the Weather Bureau for information as to when protective measures should be taken.

(*i*) *Fruit Frost Warnings.*—This service is maintained in a number of important fruit growing sections of the country, particularly in California and Oregon. A killing frost without warnings or protective measures means disaster to the crops. So important has the work become that a trained meteorologist is assigned to important districts during the frost danger season to determine how low the temperature will fall and to advise as to the extent of the protective measures that must be taken.

(*j*) *Forecasts for Alfalfa Growers.*—Special warnings are issued for alfalfa seed growers in the principal seed producing sections of the West, and for alfalfa hay making in nearly all sections from the Mississippi Valley westward. Frosts are frequent at about the time alfalfa seed is maturing and are very damaging to unharvested crops. It is estimated that near harvest time, the crop increases in value at the rate of about five dollars an acre during each twenty-four hours; if it is cut too early, much loss is sustained but a heavier loss may result from frost if not cut early enough. On the receipt of a warning, the growers vigorously push harvesting operations to save as much seed as possible.

In addition to the seed growing service, fair weather warnings are sent to all the principal alfalfa growing districts of the West during the hay-harvesting period. In Oklahoma alone two thousand alfalfa growers receive these special forecasts which are distributed through the County Agents of the Farm Extension Service.

(*k*) *Fruit Spraying Forecasts.*—A special fruit spraying service is maintained in New York and other important fruit growing districts, by which special forecasts are made for the benefit of fruit growers during the spraying season. The effectiveness of spraying depends largely upon the weather conditions at the time and immediately after spraying, and this service is of much value in supplying information as to the best time at which this work should be done. This service has been so successful that requests are on file for the establishment of similar work in a number of districts not now covered.

2. Highway Weather Service

This service consists of the issue of bulletins, daily, semi-weekly, or weekly, depending on locality, giving the conditions of the main highways in the section in which the distribution centre is located, and their passability as affected by rains, heavy snows and other conditions. Detours and other pertinent information are included. Bulletins are issued at about 50 stations in 30 states. These bulletins are used by travelers in determining journeys and routes, in the dispatching of truck, determining loads, etc.

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3. Aerological Investigations; Forecasts and Warnings in Aid of Aviation

This work involves the obtaining of free air data in different parts of the United States for the purpose of making these data immediately available for the information and assistance of the forecasters of the bureau, army, navy, and post office fliers. The observations also are summarized, studied, and the data published for the purpose of furnishing reliable information as to free air conditions for the benefit of aviation in general and especially for the aviation and artillery services of the army and navy.

Advices to the Navy crews, for the trip from Newfoundland to the Azores, were based to a considerable extent upon free air observations over the ocean. The N. C. 4 reached her destination and the other two landed close enough to the Azores so that their crews were rescued. Without the wind assistance as predicted none of these seaplanes could have flown as far, and the crews would probably have perished.

The British dirigible R. 34 left this country for England just in time to prevent being swept away by a high wind. The forecaster based his warning partly upon upper air observations. Its officers have stated that had not the warning been received the air ship, valued at more than $1,000,000, would have been lost.

The N. C. 4's recruiting trip during the autumn was successful from beginning to end largely because her pilot followed the weather forecasts, which were based partly on upper air observations.

There is no authenticated instance in which an aviator has had an accident due to bad weather, when favorable weather had been predicted.

4. Marine Meteorology in Aid of Navigation; Vessel Reporting

Meteorological observations taken on ships plying all the seas of the world are collected, charged, and discussed, and the information furnished to the Hydrographic Office of the Navy and published in the pilot chart issued by that office. The information is also made available for vessel owners, ship builders, and others engaged in work relating to ocean navigation. Moreover, the information is of value and assistance to the forecasters in preparing weather forecasts, storm, hurricane and other warnings. A full understanding of the meteorology of the ocean is of tremendous economic value in determining the safest and best voyage routes, the location of dangerous storm areas and meteorological facts of value to mariners.

Vessel reporting stations are maintained at Cape Henry, Va., Sand Key, Fla., Point Reys, Calif., and North Head, Neah Bay, Tatoosh and Port Angeles, Washington, for the purpose of reporting to ship owners the passage of vessels in and out of straits or capes at a distance from the port of destination. This gives owners several hours advance notice of the docking of ships and enables them to assemble stevedores and make other arrangements regarding loading and unloading, etc.

5. Evaporation and Run-off Investigations

Evaporation investigations are conducted in certain arid and semi-arid regions of the west for the purpose of determining the loss of storage water by evaporation. These results are of direct value to engineers in planning city water supply systems and water and irrigation reservoirs.

A special project is being conducted at Wagon Wheel Gap, Colorado, in coöperation with the Forest Service, which involves the study of the effect of forest covers on stream flow, erosion, and run-off. The scheme involves the making of continuous observations in two nearly similar water sheds in their natural forested condition for a term of years; then to denude one of the water sheds and continue the observations for a similar period of years for comparative purposes.

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6. River and Flood Work

This is one of the most valuable and important activities of the Weather Bureau. Service is maintained on all of the navigable rivers of the United States, their tributaries and water sheds. Gages are located at suitable intervals on the rivers for determining water stages and rain gages distributed throughout the water sheds. Stage readings and precipitation are telegraphed daily to district centers where the observations are tabulated, summarized and published on the daily weather maps or in bulletin form. When conditions warrant, warnings of floods are disseminated to all affected interests in the flood areas by telegraph, telephone and other means.

The saving which results from this service consists in transferring goods, stores and other movable property to places of safety. In the south and southwest live stock is pastured in river bottoms many of which are subject to overflow in time of flood. A notice of the coming of the flood permits the owner of the live stock to drive it out of the bottoms, and to safeguard any other movable property that may have been left in the threatened region. Forecasts of extreme low river stages are also of much value to navigation in many rivers.

7. Mountain Snowfall and Water Supply Investigations

This service is maintained in the western states in order to give dependable information relative to the seasonal snow cover, its depth and water content. This information is valuable in determining the probable water supply that will be available both for irrigation and power purposes in those states having little or no rainfall in the summer months.

8. Climatological Work

This work consists of the collecting, compiling, charting, and discussing climatological data of the United States, its adjacent oceans and outlying territories. In addition to the observations taken at the more than 200 regular stations of the Weather Bureau, observations of temperature, weather, precipitation, etc., are taken by cooperative observers located in practically every county of the United States. These observations are compiled and printed monthly and disseminated to the public, to commercial exchanges, farmers, engineers and home seekers and many other classes. The value of this work is incalculable. It affects and benefits the entire people; is used in the settling of damage claims, cases at law and for other purposes too numerous to mention. In New York City alone the weather records are brought into court by personal appearance of a Weather Bureau official more than 500 times a year. Several thousand certificates are issued annually over the seal and signature of the Secretary of Agriculture for court use. More than 100,000 people annually make inquiry and are furnished statements regarding past weather records. The economic value of the climatological work of the bureau is enormous.

9. Agricultural Meteorology

This service consists in the collection and dissemination of information relative to the effect of current weather conditions on farm activities, the growth of vegetation and the development of crops and their advancement as compared with an average season. Advice is given and information disseminated relative to the utilization of the special forecasts and warnings issued by the Weather Bureau in the interest of various lines of agriculture and horticulture and stock raising. A number of lines of investigations are being conducted as to the relationship between weather conditions at various periods of the growing season and crop yields.

(*a*) *Weekly Weather and Crop Bulletins.*—The National Weather and Crop Bulletin issued weekly at Washington contains a detailed summary of the weather conditions throughout the country for the period covered by each issue and indicates the resulting

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effects on the development of vegetation and farm activities in general. In addition, the Bulletin contains from time to time charts and discussions bearing on the relation of climate to crops and agricultural operations.

The value of this publication is evidenced by the popular demand for it, which has grown to such proportions as to severely tax the printing facilities of the Bureau. There are about nine hundred paid subscriptions to this publication and about twenty-seven hundred other recipients.

In addition, a weather and crop summary is issued during the active agricultural season at each state center, forty-two in number, which is disseminated by bulletins and through the public press.

These services are of much value to those interested in agricultural operations throughout the country, as they afford detailed information as to the prevailing weather in all sections and its effect on farming operations and crop development.

(*b*) *Corn and Wheat Service.*—This service is maintained during the active growing season of each year, April 1 to September 30, in sixteen principal grain states. Daily weather reports are received from one hundred and eighty-seven special reporting stations. Daily bulletins are issued from nineteen points. A weekly corn and wheat region bulletin is issued also at the regional center, Chicago, Ill.

This service is of especial benefit to farmers, dealers, millers and others interested in the cereal crops of the United States, and gives accurate information as to prevailing weather conditions throughout the principal producing areas during the period of crop development. There are constant and persistent demands for extensions of the service into regions not now covered.

(*c*) *Cotton Region Service.*—This service is similar in organization and operation to the corn and wheat region service, and covers the cotton growing states of the country. About two hundred reporting stations are maintained. Bulletins are issued from 26 stations located in the cotton belt. The service is maintained in the interest of cotton growers and others engaged in various lines connected with the industry. It is considered by cotton growers and dealers to be of indispensable value.

(*d*) *Cattle Region Service.*—This service is maintained for the collection and dissemination of information of current weather conditions over the great grazing districts of the west and southwest as affecting the stock industry. Weekly bulletins are issued from a number of central points throughout the year, giving information as to rainfall, temperature, snowfall, and general grazing conditions on the ranges.

10. Solar Radiation Investigations

The importance of sunshine as a weather and climatological factor is fully recognized by meteorologists, climatologists, biologists and others. Until a comparatively recent time, only the duration of sunshine has been recorded. The object of the solar radiation investigations is to measure the intensity of the sun. These data have not only direct application to agriculture, but have a value in many other ways. Illuminating engineers have for a long time been asking for measurements of daylight or sunshine intensity expressed in light units. This information is of special value to them in connection with the designing of factories and other buildings to meet the requirements of state laws relative to natural light.

11. Seismological Investigations

The object of these investigations is to determine how frequently on the average and how severely the various portions of the country are shaken by earthquakes. From the data thus collected, it is determined what sections of the country are seismic; just where the active cracks are, and their liability to further slips or movements. This information is of prime importance in enabling engineers to avoid the placing of aqueducts for city water supplies, dams and other structures on or across fault lines.

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12. VOLCANOLOGICAL INVESTIGATIONS

This work is now confined to studies of the activity of the Kilauea Volcano located on the Island of Hawaii. It has been conducted by the Weather Bureau for little more than a year, is scientific in character, and it is impracticable at this time to assign thereto any pecuniary return to the people.

APPROPRIATION

The appropriation for the Weather Bureau for the fiscal year ending June 30, 1920, amounted to $1,880,200, almost the whole of which is expended for public service, and under existing conditions but little is available for investigation and research. It is very easy to show that benefits accrue to the United States in the proportion of much more than one thousand to one.

PROBLEMS OF METEOROLOGY

It is now necessary to carry on all the practical routine functions of this service while the forecasters and officials are still doubtful concerning many of the most fundamental and important laws and causes of the atmospheric phenomena with which the science deals.

Education.—Very few of the great universities carry any courses in advanced meteorology. In fact, meteorology receives far less attention in the institutions of learning than is given to almost any other branch of science. Tendencies to the more profound recognition of meteorology in education are in evidence, and it is earnestly hoped that much more intensive attention can be given to this science in view of its enormous practical importance in the everyday life of humanity.

Meteorological Laboratories.—Progress in other lines of science has been made in many cases by leaps and bounds through the establishment of laboratories for the conduct of specific investigations. The really great problems of meteorology cannot be brought within the domain of a laboratory, and no real meteorological laboratory yet exists, although certain elemental phenomena of meteorology admit of investigation in the best physical laboratories. Progress is delayed, no doubt, because of the inability to subject the great major phenomena of meteorology to laboratory and controlled investigation. The difficulties involved in these considerations appear to be inherent and insurmountable, leaving to the student only the alternative of minutely analyzing the complex mass of meteorological data, with the view to working out the more or less indefinite correlations and the coefficients of involved equations representing all the factors in operation in arriving at any particular result. The masses of data available are enormous, and meteorology has been criticized for continuing to accumulate, as it must from other important considerations, observations of every sort of atmospheric condition while its discussion is sadly neglected. Students are needed to study this mass of data, and it is often difficult to know where to begin or how to proceed.

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Meteorology of the Oceans.—While the mass of data available for land and continental areas is very great, the details of information available from the larger expanses of ocean areas are correspondingly meager and inadequate. Owing to the uniformity of conditions over the ocean areas, as well as their tremendous extent, we should expect the sequence of atmospheric phenomena to be more simple and easy of investigation. The collection of more complete data from ocean areas and its intimate analysis and discussion are, therefore, most important.

Aerology.—The term *aerology* has come recently to be applied to the meteorology of the free atmosphere in contrast to observational data dealing specifically with surface conditions. The appliances and agencies for conducting observations in the free air have been improved, multiplied and made highly practical, and the attainment of practical navigation of the air has not only added to the observational possibilities but has imposed new and important obligations on the meteorologist to make applications of his science to the aid of aerial navigation. Free air observations over the oceans especially are greatly desired, although very difficult to secure. The whole field of investigations in the free air is relatively only recently occupied and appears to be fruitful of the most important developments. The organization of systematic studies of upper air observations to be carried on concurrently with the making of the observations is at once among the foremost problems awaiting consideration.

WORLD METEOROLOGY

The development of the so-called world meteorology as typified by the collection, summarization, and publication of simultaneous weather reports from all civilized countries has been the goal of meteorologists for many years. The desires of a number of international meteorological conferences in pre-war days are being realized by the publication the "Réseau Mondial" by the Meteorological Office of England. The "Réseau Mondial," however, provides only for monthly summaries of pressure and temperature.

In 1914 the Weather Bureau began publication of a daily chart of pressure and temperature of the Northern Hemisphere from telegraphic and cable reports. The machinery for the collection of the data was put out of commission during the war and has not yet been restored.

In considering the resumption of this undertaking it may be viewed from a totally different angle than formerly, viz., is it not possible by sacrificing the time element to prepare a daily pressure and temperature map of the Northern Hemisphere—say 30 to 90 days after the current dates have elapsed, such maps to serve for study purposes only and to be reproduced in a small edition?

Closely coupled with the above proposition is the need already mentioned of more frequent meteorological observations over the oceans,

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more especially the Pacific. In this connection reference may be made to the Committee of Exploration of the National Academy of Sciences which has had under consideration for several years plans for the exploration of the atmosphere over the Pacific. What I have more particularly in mind, however, is the necessity for more meteorological observations from vessels navigating the Pacific. The ordinary means at our command that can be applied to stimulating interest in meteorological observations by vessel masters may not be sufficient to procure an immediate response to this need. In any event it will be helpful and necessary to secure the active coöperation of all the great dominating interests concerned in the development of the Pacific area.

UNIFORMITY IN PUBLICATION

The one great handicap to the use of the accumulated meteorological data is the fact that adequate summaries for representative stations in different parts of the globe are not available. An important forward step will have been taken when the various meteorological services shall agree to compile according to some uniform plan and publish monthly and annual summaries for representative stations under their jurisdiction. This in effect would be an extension of the data now published by the English Meteorological Office to include other elements than pressure and temperature. The subject is one for international conference and consideration; meanwhile each country should begin the preparation of a digest of its own data for the needs of its own citizens.

TERRESTRIAL WEATHER AND SOLAR ACTIVITIES

A profound understanding of the problems of meteorology requires a correct discernment of the ultimate causes of weather. In recent years much attention has been directed to the establishment of detailed correlations between solar activities and terrestrial weather. It seems most important to proceed cautiously in a matter of this kind, since it would appear that the views being advocated by a few leaders in these investigations must be regarded with skepticism and distrust in the forms in which they have thus far been presented. All are in accord that the sun is the ultimate source of all our atmospheric phenomena commonly designated weather. It seems that the daily sequence of sunshine and darkness; the varied distribution of clear and cloudy skies; diversities of surface cover added to contacts of land and water areas, including the phenomena of evaporation, condensation, and precipitation; the cycle of the seasons, and above all the fluctuating but nevertheless perpetual contrasts of surface temperatures, ranging all the way from the heat of the tropics to the intense cold of the polar zones constitute a complex series of varied and changeable influences seemingly abundantly adequate to cause and explain every feature of our weather conditions, however changeable we may find them.

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These differences and contrasts on the one hand perpetually disturb the orderly arrangement of air densities and pressures demanded by gravity. The latter, on the other hand, as perpetually and continuously sets portions of the air in motion, in order to establish and maintain a state of equilibrium, which, however, is never attained. We must clearly recognize that *the ceaseless complex changes in and motions of our atmosphere* represent in fact the only state of equilibrium possible between gravity on the one hand and solar heating of the earth on the other.

The disposition on the part of some to attribute important phenomena of terrestrial weather to minor solar activities is believed to be a mistake. It is in fact believed that apparent changes in solar activity, especially of the thermal character, are in reality altogether of terrestrial origin and that the imaginary correlations between terrestrial and solar activities are really the simple relations between atmospheric phenomena at one point and possibly those at another on the earth itself. It is most important that these major problems of cause-and-effect relation between solar and terrestrial activities should be observed, not only with the greatest possible accuracy but that the observational data themselves should be thoroughly analyzed and discussed, first, to establish the magnitude of the errors of the observation, and second, to determine the possible relations between solar and atmospheric effects.

Seemingly the greatest need in meteorology is that of a master mind to direct itself comprehendingly and intensively to the great problems which the science still presents.

SOME OF THE CHIEF PROBLEMS IN TERRESTRIAL MAGNETISM AND ELECTRICITY

By Louis A. Bauer

1. *Analysis of the Earth's General Magnetic Field:* The early completion of the general magnetic survey of the globe, as undertaken by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and coöperating countries, will afford the necessary data for the investigation of some of the so-called "greater problems of the earth's magnetism." One of these is the determination of the various systems of magnetic and electric forces which together make up the total terrestrial magnetic field as observed at the earth's surface. It is known from previous analyses that the earth's magnetic field consists of an internal system of forces, which constitutes by far the major portion; secondly, an external system, supposedly to be ascribed to electric currents circulating in the earth's atmosphere; and, thirdly, a system possibly such as that of vertical electric currents which pass from the atmosphere into the earth and vice versa. The definite settlement of the question as to the existence of the third system is regarded by Sir Arthur Schuster as one

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of the chief outstanding problems in terrestrial magnetism. This problem involves the question whether or not the magnetic forces of the earth can be entirely referred to a potential. If not, then the question arises as to the existence of vertical electric currents, which will be of interest both to students of the earth's magnetism and of the earth's electricity, using the latter term in its most general sense so as to include electric phenomena arising from systems both below and above the earth's surface. The ocean work of the Department of Terrestrial Magnetism has been arranged with the special view of obtaining the requisite data for the solution of this interesting question. But for the war all the necessary data and the results of their discussion would be available now.

2. *Analysis of Continental and Regional Magnetic Fields:* The detailed magnetic survey of the United States—the largest land area over which magnetic surveys with the requisite accuracy and detail have been made—affords further opportunity for the investigation of the problems referred to in the previous paragraph, at least so far as the investigation of those problems can be undertaken for a limited region of the globe. In the respect that the magnetic constants of the earth's general field depend in a very large measure upon the area embraced in the investigations, problems of terrestrial magnetism differ fundamentally from those of geodesy. Concerning this point, a preliminary study was made by the writer in connection with a brief discussion of "Some Results of the Magnetic Survey of the United States" printed in *Science*, May 22, 1908, (812–816).

It was found that the magnetic forces observed at any given point in the United States are the resultant effects of (1) a general or terrestrial magnetic field arising from the general magnetic condition of the earth, (2) a general, terrestrial disturbing cause which distorts the general magnetic condition of the earth at the place of observation, related possibly in some manner to the rotation of the earth, (3) a continental disturbing effect, arising largely from that portion of the North American continent above the general ocean bed, (4) a regional disturbance caused by low-lying magnetized masses or earth-currents covering a certain region, and (5), a local disturbance to be referred to magnetized masses or currents in the immediate vicinity.

A mathematical formula of limited spherical harmonic terms based upon the entire earth cannot, of course, include also disturbances of such restricted areas as are embraced under Nos. 4 and 5, namely, regional and local disturbances, but it appears that such a formula cannot adequately represent even the *continental* effects. In the spherical-harmonic formulae the terms of the various orders advance and recur by trigonometric functions of multiples of the longitude and the latitude. Thus a term involving six times the longitude is supposed to continue around the earth six times in unaltered manner. However, such a term arising, for example, from the North American continental shelf, which in the

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United States has a width in longitude of about 60°, would not continue around the earth but would in all probability die out before the European or the Asiatic continent is reached. In brief, the higher harmonic terms of the mathematical formula introduced by Gauss and based on the potential theory, could at the best but simulate or "counterfeit" the facts of nature and not represent the actual truth.

Thus the question arises how far it is really worth while to proceed in the establishment of such a theoretical formula. Although the mathematical expressions may be extended so as to include forty-eight or more unknowns, it has been found that the computed results, magnetic declinations, for example, depart so much from the actual observed results—several degrees—that they could not be used even for purely practical purposes such as those of the surveyor and the navigator. The conclusion therefore reached was that it may be found sufficient for many purposes to restrict the theoretical formulae to a certain finite number of terms involving a limited number of unknowns which represent, from a physical standpoint, the chief and principal facts of the magnetic condition of the earth, as resulting, for example, from system (1) mentioned above, or perhaps better, systems (1) and (2). The magnetic field represented by this limited expression might be called the normal, or reference field, just as the geodesist, who restricts the constants to be determined for the figure of the earth to two or three, calls his adopted figure, the "spheroid of reference." Residuals from the magnetic field of reference would then receive separate or special treatment in accordance with their extent and their character.

Respecting the existence of possible vertical currents, the preliminary analysis of the data of the magnetic survey of the United States indicated a definite system, related in some manner to the general atmospheric circulation and with an average current strength of about $^1/_{30}$ ampere per square kilometer, just as the writer had found in his previous investigations pertaining to the entire earth.[1] The additional data acquired in the United States since the preliminary analysis, will make possible a more complete investigation of this important matter. Of special interest in this connection will be found the quotations regarding Dr. Wilson's investigations (see paragraph 4).

We see then that the data obtained by the United States Coast and Geodetic Survey in the prosecution of the magnetic survey of the United States afford opportunities for interesting and fruitful research of various kinds. There may be mentioned, for example, the correlation between magnetically disturbed areas and geological formations or local deviations of the plumb-line, in which Section *a* (Geodesy) is also interested. Possibly also the data obtained in the United States may throw some light ultimately upon the problem as to the variation of the magnetic elements with altitude, and upon the question as to the effect of local or regional disturbances upon the secular changes of the earth's magnetism.

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3. *Effect of Altitude upon the Earth's Magnetic and Electric Elements:* One of the important problems, both from a practical and a theoretical standpoint, is that of making magnetic and electric observations in the upper regions of the atmosphere. A number of investigations of extreme interest fall under this head. How the magnetic data for the United States may contribute towards the solution of some of the problems has already been stated. The preliminary analysis mentioned gave some indication of dependence of vertical-intensity residuals upon altitude. A joint investigation by the Department of Terrestrial Magnetism and the United States Coast and Geodetic Survey was made of the mountainous region about Pike's Peak, Colorado, directly after the eclipse observations of June 8, 1918. The magnetic stations ranged in altitude from about 6,000 feet to 14,000 feet. Whether any definite result may be derived from such mountain observations as to rate of variation of magnetic elements with altitude, in view of the minuteness of the probable variations, depends upon the successful elimination of the local disturbances caused by magnetic rocks. It was found that the region investigated was not wholly free from such disturbances. It will be necessary for the solution of the problem to devise instruments of sufficient sensitiveness and stability to make possible magnetic observations of the required accuracy in air ships. To show the necessity of altitude magnetic observations, it will suffice to say that an infinite number of distributions of magnetic and electric systems within the earth may be found which will satisfy observations made simply on the surface of the earth.

Complete atmospheric-electric and radioactive observations in the upper regions of the atmosphere are of fundamental importance to the problems of the earth's electric field: of its maintenance, and of its variations. It is very much to be hoped that such observations may soon be systematically carried out in the United States.

4. *Variations in the Earth's Magnetic and Electric Phenomena:* The study of these variations opens up a wide field of research of interest not only to the Section of Terrestrial Magnetism and Electricity but also to other sections of the American Geophysical Union. In investigations as to a correspondence between manifestations of the earth's magnetic, or electric, activity with the Sun's activity, one of the fundamental questions is what to take as the complete measure of activity, either for the earth or for the sun. This question also enters into certain meteorological investigations. In this way, and as appears later, some of the problems of Section *d* (Terrestrial Magnetism and Electricity) also touch upon some of those of Section *c* (Meteorology). The following quotations from the Annual Report of the University of Cambridge for 1919, relating to investigations made by Dr. C. T. R. Wilson at the Solar Physics Observatory, are of particular interest here:

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"The results obtained in these investigations have suggested a theory, which both accounts for many of the more important phenomena of thunderstorms, and relates them to those of fine-weather atmospheric electricity and terrestrial magnetism....

"The order of magnitude of the currents in thunderstorms, as indicated by the results of observations of lightning discharges, is such as to suggest the possibility of correlating the phenomena of atmospheric electricity with those of terrestrial magnetism."

5. *Magnetic Storms, Polar Lights and Earth Currents:* Many problems of interest to several sciences come under this head. The various pronounced manifestations of solar activity and terrestrial magnetic and electric activity during the past month, especially March 22–23, have called renewed attention to these problems. The magnetic disturbance of March 22–23 was world-wide and was one of the severest recorded. On the evening of March 22 one of the most remarkable displays of the Aurora Borealis was witnessed at Washington and at points in even lower latitudes; at a corresponding time there was a fine display of the Aurora Australis at the magnetic observatory of the Department of Terrestrial Magnetism at Watheroo, Western Australia. During the magnetic disturbances and auroral displays the generated earth-currents caused interruptions on cable and telegraph lines. The sun-spot activity during this period was of a very marked and interesting character. Dr. Abbot reported that the solar constant, as observed by the Smithsonian Institution party at Calama, Chile, on March 23, had reached the low value of 1.866, whereas from January 1 to March 22 it had varied from 1.93 to 2.00; on March 24, the value was 1.905, and thereafter it went up again. This case illustrates well the joint interest of various sciences.

The general effect of magnetic disturbances is to diminish for a time the intensity of magnetization of the earth's field, in severe cases as much as ten percent. It took about three months after the severest magnetic storm on record, the one of September 26, 1909, before the earth's magnetic intensity had returned to its approximate normal value. An interesting theory[2] of magnetic storms has recently been advanced by Prof. F. A. Lindemann, director of the Department of Physics at the Univeristy of Oxford. To overcome some of the difficulties of Dr. Chapman's theory[3] of a stream of charged particles, Lindemann suggests the alternative of clouds of ionized gas ejected from the Sun and driven away by light-pressure. Such a cloud would be completely ionized, and therefore invisible; it would be kept generally together because it contains both positive and negative ions; and yet it would expand sufficiently to satisfy observed facts about the duration of magnetic storms as the earth passes through the cloud—in our upper atmosphere the ions would recombine and cause the storm. The theory is worked out quantitatively and found to satisfy known facts.

6. *Magnetic and Electric Observations During Solar Eclipses:* Intensive observations under this head have been made, especially since the total

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solar eclipse of May 28, 1900, which occurred in the southeastern part of the United States, the writer being then in charge of the magnetic work of the Coast and Geodetic Survey. Nearly every prominent solar eclipse since then has been taken advantage of and coöperative observations over the entire globe have generally been made in accordance with a program outlined by the Department of Terrestrial Magnetism. Briefly stated, the general result has been that an appreciable magnetic effect, though of a minute order, is recorded during the period of a solar eclipse, similar in character to the variation experienced by the earth during a solar day, and differing from it only in magnitude. It is believed that the detection and study of an eclipse magnetic effect will be of great importance to theories of the earth's magnetic field and of its variations.

During the famous solar eclipse of May 29, 1919, the Department of Terrestrial Magnetism had two expeditions in the belt of totality: at Sobral, Brazil, under the charge of D. M. Wise, assisted by A. Thomson; and at Cape Palmas, Liberia, under the writer's charge, assisted by H. F. Johnston. At Cape Palmas there was experienced the longest totality (6 minutes, 33 seconds) enjoyed by any of the eclipse parties. The geophysical observations at the two stations will have an important bearing upon the complete interpretation of the light deflections observed by the British expeditions stationed at Sobral, Brazil, and the Île of Principe.[4]

Besides the magnetic results, interesting electric results were also obtained at Sobral, which, briefly stated, are:[5]

a. The potential gradient showed a well-formed minimum beginning with totality and extending until about 20 minutes after totality; the values observed during this period were about 20% lower than the mean derived from two equal periods immediately preceding and following it. *b*. During the period of potential-gradient minimum the fluctuations of the gradient were very much smaller than during the similar periods preceding and following. *c*. The positive and negative conductivities (and, therefore, the total conductivity also), each showed an increase of the order of 20%, beginning just after totality and continuing for about 15 minutes. *d*. The air-earth current density (product of simultaneous values of potential gradient and total conductivity) showed a greater constancy during the period in question than for any equal period throughout the forenoon of the day of the eclipse.

The results for May 29, 1919, at Sobral, are in general agreement with those obtained at Lakin, during the eclipse of June 8, 1918,[6] notwithstanding the great difference between the two stations as regards latitude, elevation, general topography, and distance from sea.

7. *Terrestrial Magnetism and Seismology:* Records of seismic disturbances are frequently obtained on magnetograms and thus arise problems of joint interest with the Section of Seismology. Prof. Reid has made a special study of these magnetograph records and finds that the oscillations

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of the magnets producing the records are chiefly mechanical in their origin.[7]

8. *Terrestrial Magnetism and Electricity, and Physical Oceanography:* The problems of joint interest to the two sections relate to the magnetic and electric observations over the oceans, the delineation of disturbed regions, especially near ports, the effect of ocean depths on changes of the magnetic elements as observed over the surface, etc.

9. *Terrestrial Magnetism and Electricity, and Volcanology:* Besides local changes in the distribution of the earth's magnetic forces in the neighborhood of volcanic eruptions, there are other points of joint interest to students of volcanology and of terrestrial magnetism and electricity. As an illustration may be cited the remarkable circumstance of a world-wide magnetic disturbance which took place almost simultaneously over the entire earth, beginning at 7 h. 54 m. St. Pierre local mean time on May 8, 1902. According to the reports at the time of the Mont Pelée eruption the town clock at St. Pierre was found stopped at 7 h. 50 m.; how accurately this clock kept local mean time is, of course, not known and it may be that the time as obtained from the magnetic records will have to be regarded as the most accurate determination of the beginning of that remarkable eruption. Magnetic disturbances occurred again during the eruptions of May 20 and May 21, 1902.

At the meeting of the "Congress of Arts and Science," held at St. Louis, 1904, L. A. Bauer gave a preliminary discussion of the magnetic disturbances just referred to in connection with his paper on "The Present Problems of Terrestrial Magnetism."[8] The precise causal connection, if any, between the Mont Pelée eruption and the magnetic disturbance has not been completely worked out at present. The connection may have to be sought through the fact that there were remarkable electric phenomena during the eruption which may have caused a sufficient change in the electrification, or in the electric currents, of the earth's atmosphere to have produced in turn a magnetic effect.

During the eruption of Krakatoa, Java, of 1883, there was no world-wide magnetic disturbance. However, a local disturbance, of discontinuous character, occurred at the near-by Batavia Magnetic Observatory, this disturbance lasting merely during the rain of volcanic ashes upon Batavia, and the magnetic effect was attributed by the director of the Batavia Observatory to the magnetic character of the ashes. The electric phenomena in connection with the Krakatoa eruption were also very marked and changes of interest to students in terrestrial electricity may have occurred.

The question of electric currents in the earth's crust in connection with volcanic eruptions is also a matter of interest. Thus Palmieri[9] made earth-current observations in the vicinity of Vesuvius during the period 1889–1893. His observations seemed to show a parallelism with the

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activity of the volcano. He furthermore found that the action of Vesuvius was such as to mask the diurnal variation in the observations of earth currents.

Reference may also be made to the investigations by Folgheraiter and others in Italy, B. Brunhes and P. David, in France, with regard to the magnetization of lava beds.

10. *Laboratory Problems in Terrestrial Magnetism and Electricity:* One of the prime purposes of the Section of Terrestrial Magnetism and Electricity should be to stimulate research in these fields as widely as possible so as to increase the number of workers, especially at our universities. About the middle of the last century very much of the investigational work in the United States in the subjects here considered was carried out by university professors. It must be one of our endeavors therefore to present and suggest problems which might be advantageously taken up at universities, either in connection with laboratory work or field investigations, over a region of greater or less extent.

Among some of the problems for experimental and theoretical investigation may be mentioned those with regard to the origin of the earth's magnetic field, origin and maintenance of the earth's electric field, improvement of instrumental appliances for magnetic and electrical measurements on the surface of the earth and at altitudes above, the effect of pressure upon the critical temperature of magnetization, studies in magnetism, in general, etc.

In conclusion, let it be stated that the incompleteness of this sketch of some of the chief problems of concern and interest to the Section of Terrestrial Magnetism and Electricity is fully realized. Other topics of importance could profitably have been dilated upon, especially with regard to the question of the origin of the earth's magnetic field and as regards certain outstanding problems in the fruitful subjects of atmospheric electricity, earth currents, polar lights, upper-air electric phenomena bearing upon radio-telegraphy, etc. It must suffice, owing to the limits imposed upon the present paper, merely to have called attention to these additional problems, and to reserve fuller treatment for a subsequent occasion. It is hoped, however, that enough has been said to show the intimate relation of the various problems not only to the sister branches of geophysics represented by the other sections of the American Geophysical Union, but also to the general subjects of physics, astronomy and geology.

[1] See *Terrestrial Magnetism and Atmospheric Electricity*, **9**, 1904 (127, 128).

[2] *Philosophical Magazine* for December, 1919 (669–684).

[3] *Proceedings Royal Society, A*, **95**, 1918 (61–83); also *Monthly Notices of R. A. S.*, Nov., 1918 (70–83); and *Observatory, London*, **42**, No. 539, May, 1919 (196–206).

[4] See L. A. Bauer's "Resumé of Observations Concerning the Solar Eclipse of May 29, 1919, and the Einstein Effect," *Science*, March 26, 1920 (201–311).

[5] See article by S. J. Mauchly and A. Thomson, *Terrestrial Magnetism and Atmospheric Electricity* for June, 1920.

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[6] *Terrestrial Magnetism and Atmospheric Electricity*, **24**, June, 1919 (96).

[7] See *Terrestrial Magnetism and Atmospheric Electricity*, **19**, 1914 (57–72, 189–203); also *Bulletin of the Seismological Society of America*, **4**, 1914 (204–214).

[8] See *Publications of St. Louis Congress of Arts and Science*, **4**, 1904 (750–756).

[9] Palmieri, L., "Osservaziones delle correnti telluriche," *Rend. d'Acad. Napoli*, **3**, 1890 (225, 250); **4** (164, 228); **5** (216).

THE PROBLEMS AND FUNCTIONS OF THE SECTION OF PHYSICAL OCEANOGRAPHY OF THE AMERICAN GEOPHYSICAL UNION

By G. W. Littlehales

The former and present function of the ocean in the history of the earth and in its economy has forged bonds of kinship between oceanography and many other branches of science. Ever since the ocean became the world-encompassing highway of communication, its surface aspects, embracing the movements of the waters in waves, tides, and currents, have been subjects of observation. With the advance of the physical sciences and a knowledge of the extent of the ocean came the realization that so large an expanse of a substance having the highest known capacity for heat must, to a large extent, govern the external temperature of the earth and exercise an important influence as a factor in geophysics. But centuries of voyaging did not extend marine observations beyond the delineation of coasts and the service of navigation; and, in the middle of the nineteenth century, the sea remained unfathomed, and the observations of the physicist, the chemist, the geologist, and the biologist did not extend beyond the shallow coastal waters.

In setting forth the principal deep-sea expeditions, by nations and states, through the names of the vessels engaged and the period of their service, we shall serve ourselves the purpose of reflecting the progress of the attempts that have been made to ascertain the physical characteristics of that vast region of the earth's surface which is occupied by the deeper waters of the ocean:

Austria
Pola (1891–1910).
Belgium
Belgica (1897–9).
Denmark
Ingolf (1895–6).
France
Travailleur, Talisman (1880–3).
Caudan (1895).
Français (1903–5).
Germany
National (1889).
Valdivia (1898–9).
Gauss (1901–3).
Planet (1906–14).
Great Britain
Lightning (1868).
Porcupine (1869–70).
Challenger (1873–6).

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Investigator (1887–1902).
Discovery (1901–4).
Scotia (1902–4).

Holland
William Barents (1878–84).
Siboga (1899–1900).

Italy
Washington (1881–2).
Vettor Pisani (1882–5).

Norway
Voringen (1876–8).
Fram (1893–6).
Gjoa (1903–5).
Michael Gars (1900-20)

Russia
Vitiaz (1886–9).

Sweden
Vega (1878–80).
Antarctic (1901–3).

United States
Albatross (1883–1920).
Blake (1876–97).
Narragansett (1871–3).
Nero (1900).
Thetis (1895).
Tuscarora (1873–6).

Principality of Monaco
l'Hirondelle (1885–8).
Princesse Alice I (1891–7).
Princesse Alice II (1895–1914).

These expeditions and many others of lesser import, operating for the most part in seas remote from the countries in which they were fitted out, have contributed much of the literature of oceanography in which we find set forth the dynamic meteorology and climatology of the ocean, the theories of the tides and waves and the observed facts concerning them, the depths of the ocean, the temperature, the composition and circulation of oceanic waters, the nature and distribution of marine organisms at the surface and in the depths, and the origin and distribution of marine deposits over the floor of the ocean. But the ocean is so vast that the accumulation of facts of observation concerning it—extensive though it be—is but a sparse array in geographical distribution and constitutes but a skeleton of knowledge in relation to the configuration of its basins, the nature and distribution and thickness and stratification of the deposits which cover the bottom, and the physical and chemical properties and movements and mode of operation of its waters in producing their effects in the economy of the earth.

It is not alone through expeditions upon the ocean that oceanography has progressed; investigations in marine laboratories and institutions of research and discoveries in cognate sciences have sometimes yielded more advancement than distant and perilous voyages.

Advancement in the nature of the application of the philosophy of method has enabled oceanography to profit in its later stages of development. The system according to which progress is now being sought is the study in detail of definite stations in the ocean occupied in concert, and, as we hope it will be, by international coöperation, and periodically revisited for the purpose of observing the variations of physical condition whose import, when it comes to be understood, will enhance all those wealth-producing sources which operate in seasonal cycles. Observa-

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tions of temperature, salinity, gas content, and currents made as nearly as possible at the same instant at series of points or stations and throughout a network of lines distributed in the depths beneath a given area of the ocean, and repeated every three months have afforded the means of making synoptic charts which disclose the existence of bends or undulations like the waves formed on the boundary surface between water layers of different densities. It is the mathematical investigation of the variations with time of the changing network of lines of equal values of the physical elements in their distribution in the depths that promises to introduce oceanography into the ranks of the exact sciences by enabling oceanographers, by mathematical laws, to predict effects from a few observations strategically placed.

Conspicuous among the features of the resumption of American oceanographical operations, after the interruption occasioned by the exigencies of the late times, are the following: The International Ice Observation and Ice Patrol Service in the North Atlantic Ocean, employing the vessels of the United States Coast Guard under an arrangement by which the cost is shared proportionately by the nations participating in the London Conference of 1913, is engaged (coördinately with the primary duties of ascertaining the locations and progressive movements of the limiting lines of the regions in which icebergs and field ice exist in the vicinity of the Grand Bank of Newfoundland and the dissemination of the information so ascertained for the guidance and warning of navigators) in gathering an important accumulation of oceanographical and meteorological observations. Year by year, observations at recorded times, extending from the surface to the bottom, are made in well determined geographical positions throughout the patrolled region for determining the temperature and salinity of the water by readings in series at definite depths, the direction and rate of movement of the waters in the different depths, the collection and preservation of plankton and samples of the water from ascertained depths, and in recording the state of the weather and the sea together with the barometric pressure, the humidity and the temperature of the air. These observations are published annually in the Bulletins of the United States Coast Guard, Treasury Department.

Closely related to these investigations from the standpoint of the advancement of oceanography, is the accumulation of observations resulting from the annual returns of the schooner Grampus in the Gulf of Maine and its vicinity, for the study of the correlation between physical oceanography and biological oceanography in these waters, under the joint auspices of the United States Bureau of Fisheries and the Museum of Comparative Zoölogy of Harvard University.

At La Jolla, near San Diego, California, there has grown up an institution by the name of the Scripps Institution for Biological Research, whose operations, recently brought under the auspices of the University

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of California, constitute an exemplar of intensive oceanographical investigation. By systematically and repeatedly tabulating and mapping standardized values of the temperature, salinity, density, currents, and gas content of the water of the Pacific Ocean, serially observed at ascertained intervals of depth from the surface to the bottom in fixed locations, the variations of these physical elements, with time and locality, in their distribution in the depths, have been revealed to an important extent within the confines of the oceanic tract in the region of the seat of the Institution, stretching from San Diego to Point Concepcion and embracing an area of more than 10,000 square miles.

It is the present purpose of the Section of Physical Oceanography to foster the labors of these agencies and the similar ones which are contributed by the Navy and the Coast Survey and to seek opportunities to supplement them and link their operations, as far as may be, into coördination with the operations of the oceanographers of Japan, of Australia and New Zealand, of the North Sea International Council of Exploration, and the Mediterranean Sea International Council of Exploration. And, through the formation of committees, to provide that consideration shall be given to the problems of evaporation and heat transference and the interrelations between oceanography and meteorology, to the problems of dynamic oceanography including the variations of mean sea-level and the tides and their manifestations in the depths as well as the surface, to the investigation of the chemical and physical properties of the waters including the penetration of light, to the investigation of the origin and distribution of bottom deposits, to the problem of ascertaining the conformation and topography of the basins, and to the ways and means of advancement in the domain of physical oceanography.

THE PROBLEMS OF VOLCANOLOGY

By Henry S. Washington

INTRODUCTION

Of the various sciences represented in the American Geophysical Union that of volcanology is perhaps the most complex and has probably most points of contact with the other geophysical sciences. This complexity and variety in the problems presented by the study of volcanoes arises, in part, from the fact that they are, as has been well said, "natural laboratories." Also the distribution and many of the activities of volcanoes are closely connected with some of the physical, as well as the chemical forces that are involved in the formation and in the present condition of the earth.

In presenting some of the main problems of volcanology, we may begin with those that are essentially and more purely volcanological, and

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then take up seriatim the consideration of certain problems in which the other sciences represented by sections of the Union may enter. Because of the limitation of space only a brief enumeration and presentation will be made, and no adequate discussion will be undertaken. I am much indebted to various members of the Union for some valuable suggestions, which will be mentioned in their proper places.

VOLCANOLOGY

A word may be said as to the name of the science. The spelling, *volcanology*, (rather than *vulcanology*), has been adopted officially by the Executive Committee of the Union, following the report of a sub-committee. The decision was arrived at chiefly in accordance with the dictum of the Century Dictionary (*s. v. vulcanism*): "The words *volcano* and *volcanic* are firmly fixed in English, and the former is in universal and exclusive use among those who speak that language. Hence all the derivatives should be spelled accordingly."

It is now well recognized that there are different types of volcanoes, distinguished by their form and structure, as well as (generally) by the differing kinds of volcanic activity, and that these differences are to a large degree dependent on, or at least coincident with, the differing chemical types of the volcanic material, such as, for instance, whether rhyolitic, andesitic, or basaltic. It follows that the activity or form of any one volcano, such as Vesuvius, Kilauea, or Stromboli, cannot be taken as typical of all volcanoes generally. This important principle does not seem to be generally recognized.

One of the first and most fundamental needs for the proper study of volcanoes is the compilation of a complete and fairly detailed catalogue of volcanoes (suggested by Wood and the writer). Such a catalogue should list all known active, dormant, or recently extinct volcanoes. It should give briefly, so far as known or ascertainable, the geographical position; the hypsometrical and areal data, including those of the crater; the general petrographical characters of the lavas, with the general order of succession of the different types; whether active, dormant, or extinct, with the geological period of commencement if possible; the general types of volcanic activity; a chronological list of the known eruptions, with some indication of the degrees of intensity; and a bibliography of the chief sources of information as to each volcano; with possibly such other data as may present themselves.

The older lists, as those of Daubeny (1848), Landgrebe (1855), Scrope (1862), and Fuchs (1865), are far from being complete; while even the more recent ones, such as that of Mercalli (1907), though they list many volcanoes not known to the earlier volcanologists, are yet themselves not complete, nor do they give many of the varied data mentioned above as desirable. The compilation of such a catalogue might be entrusted to a special committee.

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Another great desideratum is the keeping of a systematic record of all known volcanic events, eruptions, indications of renewed activity, and so on. This should be as complete as possible, and might be compiled by another, or the same, special committee, possibly with the assistance of some news-clipping bureau and correspondents at various volcanoes. In such a record, and in all other official volcanological literature, the sensational features should have a minimum of stress laid upon them.

If possible, some systematic investigation of the little known volcanoes and volcanic regions should be undertaken. This applies especially to those of the islands in the Pacific and Atlantic Oceans, and Daly, in an important paper, has called attention to the paucity of our knowledge as to the first of these. It is possible that such an investigation may be started by the coming Pan-Pacific Congress at Honolulu, at which the scheme will probably be proposed. For this purpose the assistance and coöperation of intelligent persons living in, or trading among, the various islands may be obtained, as well as, possibly, that of some private expeditions. Even the collection of chance specimens from the little-known islands would be of great value.

In this connection it may be suggested that the early history of our own western volcanoes should be investigated, as by search through the records of the early explorers and settlers, for possible mention of volcanic activity, and the verification or disproof of some such reported occurrences. The lavas of these volcanoes are well known, but the character of their volcanic activity has been much neglected.

Apart from the purely scientific question as to how and why a volcano "works," is the practical, and scientifically equally interesting, one of the prediction of eruptions. Unfortunately, with two or three exceptions, we know of volcanic activity almost entirely as displayed only during eruptions, and especially major ones. It is much like studying a complicated machine only when it is working at full speed; we can understand better the relations of the parts and their working if the machine is examined when the parts are moving slowly or are at rest.

For the prediction of eruptions, and for the solution of many other volcanological problems, prolonged, continuous, and systematic observations on volcanoes are absolutely necessary, not only during eruptions, but during the quiet intervals that precede and follow eruptions. Such observations have been carried on at Vesuvius, at first by Mercalli from 1892 to 1906, and by Malladra from about 1912 to the present time. Similar observations have also been carried on for nearly ten years at Kilauea by Jaggar, at times with the assistance of Perret, and Wood. It is hoped that the very detailed observations of Malladra will soon be published; they will form an invaluable contribution to volcanology. The records of the Kilauea observing, kept by Jaggar since 1911, are especially full and detailed and constitute what would be, if published, one of the

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most valuable contributions to volcanology yet made. It is of the greatest importance to our science that both these stations be maintained, and their observations published, so as to continue the important work so well begun. And it is also important that similar stations be established and maintained at other volcanoes of types different from these two. In its type of activity Kilauea is very unusual, while Vesuvius, though more normal in its form of activity, is very unusual in the character of its ejected material. Stations for continuous observations over a long series of years are needed at volcanoes of the rhyolitic, andesitic, and basaltic (besides Kilauea) types. These should be established at volcanoes which are more or less continuously active, and with a fair prospect of some eruptions from time to time. Several volcanoes in Japan and Java suggest themselves as favorable, and there might be mentioned also Apia in Samoa, Izalco in San Salvador, Stromboli and Santorini in the Mediterranean, and some volcanoes along the Andes and in Mexico. The establishment of such stations offers, of course, many difficulties, but it would be well for the Section to bear this in mind as one of the most important, even if one of the most difficultly realizable, objects of effort.

At any such station the continuous observations to be made would be many and various, including, for instance, daily notes on the state of the crater and fumaroles, the noises emitted, the microseismic vibrations, the weather and barometric data, etc. With all this, there would be opportunity for the collection of specimens from the various flows, fumarolic salts, gases from the lava; measurement of the earlier flows; observation of the temperature of the lavas; and many other matters. The collection of volcanic gases, and study of the best methods for this, are of special importance.

It is not probable that many of these stations will be maintained, at least in the near future, and, as the study of the phenomena of great eruptions is also of great importance, it would be very desirable if some arrangements could be made (possibly international as well as national), through which any usually dormant volcano that was reported to be showing signs of renewed activity or to be in a state of eruption might be visited immediately by competent observers. This has been done for several great eruptions, such as Santorini in 1866, Mont Pelée in 1902, Vesuvius in 1906, and Sakurajima in 1914; but always in a haphazard way, thus diminishing materially the value and scope of the observations in some cases. The immense value of such visits, however, is shown by such monumental works as those of Fouqué on Santorini, the British and Dutch at Krakatoa, and of Lacroix at Pelée, of Perret, Omori, and Kato at Sakurajima, with others of scarcely less importance. It may be mentioned here that we may hope soon to have a similarly complete and monumental report by Perret on the Vesuvius eruption of 1906.

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Among other problems with which volcanology has primarily to deal the following may be mentioned:

Study of the rôle played by earth strains is suggested by Wood, who points out that, although such factors as accumulated gas tension and possibly others, may enter, yet "a general cause of volcanic extrusion [may be] due to the so-called mountain building forces as builders of strain, and to certain variable stresses acting as trigger forces." He suggests that study of this phase of volcanology would be of interest also "to the geological seismologist, the physical geologist, and the student of isostasy." The importance of arriving at some estimate, however crude, of the magnitude of volcanic forces, possibly as a measure of crustal deformation forces, is pointed out by Wright.

A systematic and properly conducted study of thermal gradients in the crust is suggested by several (Daly, Van Orstrand, and the writer). Such a study should be carried out at carefully selected points, the stations being chosen with due regard for both the proximity and the absence of volcanoes, differences in the underlying rocks and their geological structure, the absence of secondary sources of heat (such as the proximity of ore bodies), and with proper and well-controlled means of measuring the depths and temperatures. It is reasonable to suppose that such a systematic project might be carried out with no very great difficulty or prohibitive expense. It is needless to say that the results obtained by such properly controlled means would be of the greatest value for our study of the interior of the earth, and would supersede many of the, for the most part, haphazard and not mutually comparable data that are now available.

Connected with this matter is that of the investigation of the thermal gradient and the sub-surface conditions in the mass of an active volcano, both on its flanks and within the crater. Such investigations might throw light on the rôle of gas inter-reactions as causal in the production or maintenance of volcanic heat, as has been suggested by Day, and they might also be of great practical importance in the study of the possible utilization of volcanic heat as a source of energy, a matter to which my attention was directed in Italy, both before the war and during the past year. The study of the possibilities of regions of geysers and hot springs, as the Yellowstone, and in the Hawaiian Islands, along this line, is also suggested. In this connection the present successful utilization of the soffioni at Larderello in Tuscany by Ginori Conti may be recalled.

The problem of radioactivity as a source of heat, and the possible formation of a special committee for this purpose, is suggested by Daly, who also suggests the study of the "meaning of the earth's rigidity."

As minor matters may be mentioned the study of geysers and their mode of action, and also the formation or unification of a terminology for

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lava structures, since "aa" and "pahoehoe," the two terms most commonly used, by no means cover all the types that are met with.

VOLCANOLOGY AND GEODESY

The apparently intimate correlation between the average chemical composition of the igneous rocks of the continents, oceanic floors, and of smaller petrographical provinces (as a means of arriving at comparable densities of their masses), and their elevations, together with the bearing of this study on the theory of isostasy, has been pointed out recently by the writer. W. Bowie suggests the continuation of such investigations "as a contribution to the study of isostasy." He also suggests the advisability of establishing gravity stations in the immediate vicinity of volcanoes, the selection of appropriate localities to be made with the coöperation of volcanologists. He thinks that there is reason to believe that "areas where volcanoes are active are probably in a high state of isostatic equilibrium," and the determination of this and analogous points would be of great service to both sciences.

VOLCANOLOGY AND SEISMOLOGY

At the outset it must be emphasized that, contrary to a wide-spread belief, there is little connection between volcanoes and most earthquakes, though their frequently contiguous localization may be due to one and the same cause, such as a fracturing of the earth's crust. By far the great majority of recorded earthquakes (it has been estimated at about 95%), and these the most important, are due to crustal movements and, so far as we know, have no direct connection with volcanoes or their activity. The small remainder of earthquakes of volcanic origin are mostly very local and of comparatively small magnitude. Notwithstanding this, the two sciences are in contact at several points.

The study of the small number of truly volcanic earthquakes is, of course, intimately connected with the study of the volcanoes that produce them; while, conversely, the question of the influence of earthquakes as possibly initiating volcanic eruptions or other activity is an interesting field for study.

The study of volcanic tremors of small amplitude and energy, during periods both of quiet and of eruption, is of great importance, and would naturally form part of the systematic, continuous study carried on at a volcano station, as has been done both at Kilauea and Vesuvius. This may be expected to be of very material aid in the future prediction of eruptions. For such observations some of the forms of seismographs and other seismological instruments, duly modified to suit the different conditions, are necessary, and seismological principles or data would also enter into the study.

VOLCANOLOGY AND METEOROLOGY

As has been already noted, the systematic observation of certain meteorological data, especially barometric pressures and rainfall, would form an

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important item in the routine observations at a volcano station; the former entering into the question of the "trigger forces" needed to start an eruption, and the latter as bearing on the question of the origin of the water present in volcano clouds and gases.

Humphreys called attention some years ago to the influence of the finest volcanic dust, blown into the upper regions of the atmosphere during first magnitude eruptions and suspended there for prolonged periods, in lowering the solar constant of radiation, and thus affecting the weather over wide areas for long periods. This has been invoked to account for periods of glaciation. A knowledge of the chronology of volcanic eruptions is necessary for their proper correlation with meteorological and radiation data, and the further study of this theory.

In this connection mention may be made of the possible utility of the study and identification of volcanic dust collected at great distances from a volcano in eruption, as bearing on the study of the currents of the upper atmosphere.

The possible influence of the supposed blanketing effect of carbon dioxide on past climates has long been a favorite hypothesis, and as it is known that this gas is given off by volcanoes, a possible line of research is indicated connecting climates with periods of great volcanic activity—a matter that has already received some attention.

A minor problem, and one that has been little studied, because of the rarity of its occurrence, is that of the blue or green color presented by the sun during some eruptions, as that of Krakatoa in 1883. Especial attention might be paid to this by the observers of future eruptions.

VOLCANOLOGY AND TERRESTRIAL MAGNETISM

Bauer calls attention to the "local changes in the distribution of the earth's magnetic forces in the neighborhood of volcanic eruptions." He also lays special stress on the investigation of such phenomena as the world-wide magnetic disturbance that took place coincident with the eruption of Pelée in May, 1902, and the fact that no such world-wide disturbances seem to have occurred in connection with that of Krakatoa in 1883. This is a problem in which the observations of local observers might be of great value, were their attention called to its importance and their observations properly directed. The lightning flashes in the volcanic cloud, and other such phenomena, during eruptions, are also of interest and are probably worthy of study.

Bauer also suggests the problem of electric currents in the earth's crust during volcanic eruptions, such as have been observed by Palmieri at Vesuvius. A minor point is the magnetization of lava flows, and that of clay beds covered by them; while there might also be mentioned here the study of fulgurites—the vitreous tubes and patches formed by lightning strokes fusing the rock of the summits of volcanoes, (as Ararat), and other places.

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VOLCANOLOGY AND PHYSICAL OCEANOGRAPHY

The most important point of contact between these two sciences is presented by submarine eruptions. Far too little is known of these occurrences, either as to their characters or their distribution over the ocean floors. For their study a most important and but little gleaned field of information is furnished by ships' logs, and I would suggest here the advisability of examining the thousands of ships' logs for records of submarine eruptions. This might be done through a duly appointed committee, with the coöperation of the Section of Oceanography, and with the assistance of the naval and other maritime authorities and ship owners, in whose hands the logs may now be. The data revealed by such an investigation would be invaluable for the study of submarine eruptions, and also for that of other important geophysical problems, such as earth fracture lines and lineaments, the origin of "tidal waves," etc. The submarine cable companies might also furnish valuable data on this subject from their records of broken cables, as in the case of the Aeolian Islands. I recommend this project most strongly for the consideration of the two Sections most interested.

Another problem is that of the material of the deep sea deposits, the study of which was first taken up by the "Challenger" expedition. The "red clays," as is well known, are composed largely of the decomposition products of volcanic material, and their study should be carried out more systematically and extensively than is being done at present. Further study also of the included, and too little known, chondritic and manganese nodules would also be of interest; while the study of blocks of rock (many of them volcanic) dredged from the depths also presents many features of interest. Some provision or arrangement might be made for the preservation and study by some central body of any such material that may be collected in the future. In connection with this the importance is urged of making special effort to obtain rock specimens, or sea floor deposits, from the immediate vicinity of submarine eruptions, or from areas of the sea floor that are known to be specially subject to such disturbances. These would throw much light on the petrographical and other characters of such volcanoes, and the information thus yielded would be very useful in several ways.

VOLCANOLOGY AND GEOPHYSICAL-CHEMISTRY

It is needless to dwell on the close connection between these two sciences —closer indeed than that between any other pair of the geophysical sciences. Some phases have already been alluded to on a previous page of this report, and the matter is also touched on in the portion devoted to the Section of Geophysical-chemistry. It will suffice here merely to indicate briefly some of the main points of interest.

The study of the formation of volcanic rocks and of their component

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minerals is one of the utmost importance to some phases of the study of volcanoes. Of similar importance is the study of the gases contained in volcanic and other igneous rocks, as well as of the gases given off by volcanoes in activity, with experimental laboratory study of their equilibria and possible interreactions. As is well known, all these, and similar problems form objects of investigations carried out at the Carnegie Geophysical Laboratory.

The formation of volcanic salts and other fumarole products, as well as the action of the fumaroles themselves, their temperatures and other characters, also come under the domain of geophysical-chemistry. Among other subjects may be mentioned: the determination of the actual temperatures of lavas of different compositions, and the thermal and luminous radiations of molten lava; the study of volcanic flames with the spectroscope; the melting-points or intervals of solidified lavas, especially as compared with the temperatures at which they issue; the expansion of the included gases as a factor in producing the various types of lava texture, such as the scorias and pumices; the formation of jointing through cooling, whether on a large or a small scale; the specific heats, compressibilities, thermal expansion coefficients, densities, and other physical or physico-chemical data, of rocks and rock minerals; the viscosity of lavas and its relation to temperature, chemical composition, and gas content. Many others suggest themselves, but the possible list is too long for enumeration here.

VOLCANOLOGY AND MISCELLANEOUS SCIENCES

In a previous section we have already touched on the connection with engineering in the possible utilization of volcanic heat. There may also be mentioned the application of engineering to the prevention of destruction by lava flows or eruption-bred torrents of mud on the flanks of volcanoes.

In connection with botany and related sciences there may be mentioned the subject of the effect of volcanic gases on different kinds of vegetation, a study that is being made at Vesuvius. The problems of the reclamation for agriculture of areas covered with recent lava flows or thick deposits of volcanic ashes or dust is also one of great practical importance in many volcanic regions. It may be mentioned, in this connection, that the recent expedition to Katmai, under Dr. Griggs, was undertaken primarily for the study of the vegetation of the region devastated by the eruption. Though the conditions are almost diametrically opposed, the main object was like that of the study of the Salton Sea flora by the Carnegie Desert Laboratory. Study of methods for the commercial extraction of potash from certain types of lava, as those of the Italian volcanoes, is also a matter of possibly great importance for agriculture in the future.

Finally, to leave the earth, the suggestion is made that some knowl-

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edge of the character and chemical composition of the rocks of the moon, and thus possibly a decision of the question of the volcanic or non-volcanic origin of its "craters," might conceivably be arrived at by astronomers, through study of the maximum polarization angle of various portions of the moon's surface, such as the floors of the "seas" and the "walled plains." From the determination of this, calculation of the index of refraction of the material is a simple matter. The difference between the refractive index of a rhyolitic glass (*ca.* 1.490) and that of a basaltic glass (*ca.* 1.590) is so great that it would seem to be possible to obtain some general or at least roughly approximate knowledge of the general composition of the surface rocks of the moon, especially if they are glassy lavas. We should be able, in any case, to determine thus whether all parts of the moon's surface are composed of the same material.

AN OUTLINE OF GEOPHYSICAL-CHEMICAL PROBLEMS

By Robert B. Sosman

The subject-matter of geophysical-chemistry may be defined as "the physical properties and chemical reactions of the substances and aggregates that make up the earth". It may therefore be roughly divided into two parts: A. Properties and reactions of materials accessible at the earth's surface. B. Properties and reactions of materials in the earth's interior.

Each of these may again be sub-divided as follows:

1. Properties and reactions of individual chemical substances; for example, the silicate minerals.

2. Properties and reactions of aggregates; for example, oceanic water, silicate rocks.

3. Properties and reactions of larger units of matter; for example, glaciers, batholiths.

A. MATERIALS AT THE EARTH'S SURFACE

Chemical Substances

A relatively small number of "common" oxides serves to make up practically 98% by weight of the outer ten miles of the lithosphere. All the other elements and compounds known to chemistry are included in the remaining 2%. From the geochemical standpoint, therefore, we may divide chemical substances into two classes: "abundant" and "rare."

The "abundant" oxides are, in the order given by averages of a great many analyses of terrestrial rocks, as follows:

SiO_2	About 60 per cent by weight
Al_2O_3	About 15 per cent by weight
FeO, Fe_2O_3	About 6 per cent by weight

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CaO	About 4.9 per cent by weight
MgO	About 3.7 per cent by weight
Na_2O	About 3.3 per cent by weight
K_2O	About 3.0 per cent by weight
H_2O	About 2.0 per cent by weight
CO_2	About 0.7 per cent by weight

An understanding of the chemistry of these oxides and their combinations is essential to the progress of petrology. Their study should proceed from the simple to the complex, i.e., should begin with the individual oxides, then proceed to their two-component systems, then the ternary systems, and so on. Upon this fundamental basis is then erected the structure of physical properties for each system: densities at all accessible temperatures, mechanical properties, fluidity, surface tension, specific and latent heats, etc.

The study of these systems may be divided on practical grounds into (1) investigations of the anhydrous oxides and silicates (taking in the first eight oxides in the list above); (2) investigations involving *hydrous* silicates, as well as combinations containing both carbon dioxide and water.

(1) *Anhydrous Silicates.*—Work on the first group involves high-temperature researches under ordinary atmospheric pressure conditions, except in the case of systems containing the oxides of iron, where the oxygen pressure must be controlled, and systems containing the alkali silicates, where attention to moisture, carbon dioxide, and volatility of the oxides is necessary in certain cases. Considerable progress has been made in the study of the anhydrous silicates. The phase rule diagrams of the four ternary systems of SiO_2, Al_2O_3, MgO, and CaO are now complete, and a large amount of data is at hand on the alkali feldspars, the forms of silica, portions of several quaternary silicate systems, etc.

(2) *Silicates with Volatile Components.*—Work on systems involving the volatile components CO_2 and H_2O must be done, for the most part, under pressure, and with apparatus designed especially for this purpose. The methods are well in hand and progress is being made in assembling experimental data. The theoretical side, involving the complications due to pressure as a variable in addition to temperature, is also being carried forward by several investigators.

So much for the 98%. But the remaining 2% contains many natural substances of such great economic as well as geologic interest that they must also receive attention. These may be roughly classified as in the following examples:

The Sulfide Ores (e.g., sulfides of iron, nickel, zinc, copper, lead, cobalt, cadmium, mercury, silver).—These must be studied both in their dry melts (to obtain their fundamental characteristics) and in relation to water solutions under atmospheric pressure (problems of oxidation and

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secondary enrichment). A distinct problem of the sulfides is their relation to the silicates in the igneous rocks (differentiation of sulfide-bearing bodies, as at Sudbury, Ontario).

Volcanic Gases and Salts.—These are of particular interest in their relation to volcanic activity, as at Kilauea and Vesuvius. Research on gases, including the various gas mixtures evolved from volcanic vents, is of a peculiarly trying character on account of the invisibility and intangibility of the substances handled, as well as the difficulty of collecting and transporting samples of the natural products. A special phase of this work is the study of the complex gases given off by fumaroles and hot springs. In addition to chemical composition and equilibria of the gases, data are needed on the physics of the flow of such gases from vents, as related to volume, temperature, and pressure at the point of emission.

The volcanic "sublimates", such as sulfur, ammonium chloride, arsenic sulfide, copper chloride, magnetite, may be mentioned in this connection, as well as the minerals accompanying fumarole and hot-spring activity.

The Oxide Ores (e.g., ores of iron, chromium, manganese, tin).—The study of these ores involves high-temperature investigations similar to those on the silicates, and also studies of the hydrated and colloidal oxides.

The Natural Hydrocarbons.—Organic chemistry of a very complex kind is involved in the formation and alteration of natural gas and petroleum, and many problems of physics and physical chemistry, such as adsorption, surface tension, and colloid phenomena, are also involved in their underground storage and movements.

Other substances—for example, the silicate ores, the carbonate ores, the titanium minerals—may be similarly grouped for purposes of experimental study, but it is hardly necessary here to make a complete inventory of such groups.

Running along with all these investigations is the general research necessary to develop experimental methods and apparatus, and to keep the general theory of physics and chemistry abreast of the newly accumulated facts.

Aggregates

In the preceding paragraphs we have mentioned some of the researches that are necessary on the chemical *substances* of the earth's surface. We come next to *aggregates*, including the igneous rocks, the pyroclastic and sedimentary rocks, the oceans and other bodies of water, and the atmosphere.

Igneous Rocks and Magmas.—Among the aggregates the igneous rocks are the most important, constituting as they do the original matter from which the others have been derived. They are poly-component systems with seldom fewer than six oxides, and it seems out of the question at present to give a complete phase-rule discussion of the chemistry of any

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such complex system. It does seem possible, however, to cover the field of actually occurring rocks by partial systems based upon stable minerals, themselves combinations of two or more oxides.

Experimental work has progressed far enough to show that the fusion and solidification phenomena of the igneous rocks are capable of systematic treatment of the kind mentioned above, even when the volatile components H_2O and CO_2 are included.

Following this fundamental information on the fusion diagrams, we must know the densities of the igneous rocks and their magmas at all temperatures, with their changes of volume during solidification; the textures and structures produced by various conditions of solidification; the latent heats concerned in fusion of the magma and in assimilation by it of other rocks; and many other physico-chemical data.

Some of the phenomena of differentiation of silicate rocks are probably to be treated as results of simple crystallization backed up by the effects of gravity in causing sinking or flotation of crystals. This is the only method of differentiation that has been experimentally proven, but the separation of two or more liquid phases, and perhaps other phenomena also, may take part in this little-known process.

The phenomena of the movements of igneous magmas in the lithosphere must next be attacked. This involves studies of viscosity and its changes with temperature; energy transfers accompanying movement, including perhaps the conversion of potential gravitational energy into heat energy by movement; differentiation due to movement; and the effects of the separation of gaseous constituents in causing differentiation, movements of magmas, and transfers of energy.

While the igneous rock is solidifying, processes of metamorphism may go on as a result of the passage of its more volatile constituents through the igneous rock itself and through its bordering rocks. The rise of temperature in the inclosing rocks will also initiate reactions and movements of material. The chemistry of these processes (alteration, serpentinization, contact metamorphism and replacement, formation of pneumatolytic dikes and veins) will have been included under the chemistry of the silicates with volatile components, but the rates of the reactions and the transfers of energy accompanying them must be studied as a separate problem. The question of the permeability of crystalline substances to volatile components may perhaps arise. Studies of the inversion of polymorphic forms, properties of liquid inclusions, and the effects of increased temperature on neighboring rocks must be made in order to obtain data on the original temperature of the magmas.

Sedimentary Rocks.—No sooner does the solidified igneous rock find itself at or near the earth's surface than it becomes the object of the group of processes known as "weathering." This is a subject that has been nearly at a standstill since the publication of Merrill's "Rocks, rock

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weathering, and soils" about fifteen years ago, which summarized our knowledge up to that date. It involves physical factors such as the disintegrating action of periodically fluctuating temperatures, together with the study of relative rates of reaction within and in the presence of dilute water solutions, with the complications due to colloidal phenomena and reaction in capillary spaces—a difficult field and one worthy of well-planned effort.

Rock disintegration, corrasion, and transportation, included in the general process of erosion, bring in physical and mechanical problems such as the rounding of fragments by attrition; their sorting by air and water movements; their distribution and redistribution through the agency of winds, currents, and waves; the production of particular structures such as ripple marks; the movement of unconsolidated sediments as in sand dunes, soil creep, and solifluxion; and similar questions. Reference need only be made here to summaries of these problems by Vaughan and by Merwin before the Geological Society of America in December, 1919. Experimental physics will be found deeply involved in all such problems. Colloidal chemistry will also enter, as, for instance, in the question of the precipitation and re-solution of fine suspensions; likewise biological chemistry, in the precipitation and consolidation of calcium carbonate, ferric oxide, and other products associated with organisms.

Chemical questions allied to those of weathering will enter into the problems of the consolidation and alteration of sedimentary rocks, including cementation and recrystallization, the formation of low-temperature veins, silicification, and the growth of concretions. The elastic constants of porous aggregates offer an example of the physical data that are likely to be needed in this same connection.

Pyroclastic Rocks.—The question of the origin of these rocks brings up the problem of explosive volcanism. In its larger aspects this belongs properly to the Section of Volcanology, but the products of this type of volcanic activity are very wide-spread, and the particular physical and chemical questions arising from the state of subdivision and modes of distribution and alteration of the products deserve special mention in this rather rough grouping of geophysical-chemical problems. Examples are: the molecular mechanism of the explosion, the peculiar properties of flowing dust-clouds, the physics of the projection of volcanic bombs, the sorting of products by air currents and the weathering of "ash" to form colloidal products.

The Metamorphic Rocks.—The point where a rock ceases to be "igneous" or "sedimentary" and becomes "metamorphic" is not now exactly defined, though subject to exact definition, but a distinct set of physical and chemical questions undoubtedly enters into the problems of dynamic and thermal metamorphism. The effects of *non-uniform* pressure in causing the flowing of crystalline substances and aggregates and their

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solution and redeposition, as well as the forces exerted in their recrystallization, are of particular interest. The structures resulting from movement in silicate rocks under differential pressure are in need of quantitative study. Transfers of mechanical energy and its conversion into heat are also involved. Consolidation and recrystallization as a direct result of *uniform* pressure are likewise to be considered.

Mention should be made in this connection of the physics and chemistry involved in faulting as well as in jointing and minor movements of the solid rocks. These phenomena have often been treated under the principles of elastic theory as applied to homogeneous bodies, yet there can be no question that the elastic properties and conditions of rupture of aggregates must differ in many essential particulars from those of homogeneous bodies. Here is a considerable field for experimentation.

Bodies of Water and the "Chemical Sediments".—The chemistry of the deposition of salts from sea-water has already been made the subject of special research, and van't Hoff's results in this field are already familiar. The deposition of calcium carbonate awaits a similar thorough study. Allied questions are the formation of dolomite, the deposition of various salts from inclosed bodies of water, the deposition of phosphate rocks, the precipitation of colloidal suspensions of clay and other substances, and the origin of the great deposits of sedimentary iron ore.

Problems of fresh-water bodies and streams include the chemistry of bog iron ores, and the amounts of insoluble and colloidal solids and of soluble salts carried by streams. Problems relating to underground waters may also be included here, such as: the dissolving and recrystallizing activity of underground waters; connate waters and their possible chemical changes; movements of underground waters and their relation to the alteration and concentration of gas and oil; principles of hydraulics governing the flow of wells and springs; and the characters which will serve to differentiate between vadose and juvenile waters.

The Atmosphere.—The physics and chemistry of the atmosphere considered as a chemical unit or aggregate, while logically a part of geophysics and geochemistry, are usually considered to be part of the province of meteorology; and in fact most of the investigations in this field are being made by meteorologists, or physicists employed in meteorological organizations. These questions will therefore not be further considered here. Data bearing on the origin of the earth's atmosphere and its possible changes of composition in the past—for example, the composition of the gases found in rocks and the gases dissolved by the waters of the oceans—are, however, of direct interest to the present Section.

Larger Units

The larger units of matter at the earth's surface are for the most part covered by other Sections. The atmosphere as a unit is treated by the

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Section of Meteorology and the atmospheric-electric branch of the Section of Terrestrial Magnetism and Electricity; the oceans by the Section of Physical Oceanography; the large land masses by the Section of Geodesy; volcanoes as units by the Section of Volcanology.

The larger geologic units (for example, petrographic provinces) and the rocks, considered as geologic units, might be considered to fall within the province of geology rather than geophysics, and the same may be said of the earth's glaciers and ice-sheets.

There are certain problems connected with these larger units, however, that may be neglected by the Sections mentioned, not from any lack of appreciation of the importance of the problems, but solely by reason of lack of training and lack of acquaintance on the part of their personnel with the technique involved; just as some of the geophysical-chemical problems mentioned above may be, relatively, neglected by reason of the geophysical-chemist's lack of training in other branches. For example, the physics of the flow of a glacier, considered as a unit, is not likely to be adequately handled by those trained only in the methods of glacial field geology, and it very properly becomes a subject for research under the present Section. The question of the chemical composition of a particular stratum of the atmosphere and the chemical equilibrium obtaining therein, while of great importance to the meteorologist, might fail of adequate treatment by an organization numbering no chemist on its staff. The distribution of certain rock-forming oxides according to "petrographic provinces" may be of primary interest to the geologist, yet the physico-chemical basis for that distribution—the question whether it represents an "original heterogeneity" or a result of differentiation—is a problem for this Section. The flow of rock aggregates of varying composition, again a matter of geological interest through being concerned in the processes of mountain-building, is a problem for the geophysicist. These examples will serve to indicate that there may be many points in which the Section of Geophysical-chemistry may be of direct assistance, through researches of its own type, in the work of other Sections.

B. PROPERTIES OF MATERIALS IN THE INTERIOR OF THE EARTH

The late G. K. Gilbert has made apt reference[1] to the earth's interior in these words: "Once it contained the forges of blacksmith gods; or it was the birthplace of our race, or the home or prison of disembodied spirits * * * * Science now claims exclusive title but holds it chiefly for speculative purposes." Upon the Section of Geophysical-chemistry more than upon any other will fall the duty of maintaining the validity of the title while bringing the property into productive use.

The outstanding difference of condition to which substances in the earth's interior are subjected, as contrasted with substances at the surface, is the tremendous difference in hydrostatic pressure. Research on

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the properties of substances under high pressure is thus of first importance in relation to the interior of the earth. While we cannot at present go experimentally much beyond 12,000 megabars, a pressure corresponding to about 45 km. (about 29 miles of depth), yet a really adequate knowledge of properties in this range would give us an insight into the conditions in the interior beside which our present knowledge is equivalent to almost total ignorance.

It is most important to know in this connection the compressibility of the substances concerned, at various temperatures, and in both the liquid and the crystalline state, with its dependent constants such as change of melting-point with pressure, and effect of pressure upon solubility. Other important data are: the existence of new polymorphic forms of substances; the effect of pressure upon rigidity and its related elastic moduli; the effect of pressure upon diathermancy, thermal conductivity, specific heat capacity, and magnetic susceptibility; and the effect of pressure in modifying equilibrium in homogeneous as well as heterogeneous systems.

The properties mentioned in the preceding paragraph are all properties of substances in equilibrium. The effect of pressure upon rates of reaction and rates of diffusion and crystallization are also of importance. If the planetesimal hypothesis of the origin of the earth, or some modification of it, is true, it is possible that the interior is very far from a state of chemical equilibrium, and that redistribution of matter and energy may be going forward actively, with what results—whether rising or falling average temperature, increasing or decreasing volume, etc.—it is impossible now to say.

The preceding considerations apply also to the larger units of structure of the interior—although what these units may be we can only guess—and also to the earth itself as a unit. Complex mathematical analysis is necessary in applying the data to the units of structure as well as to the whole of a body as large as the earth, where the force of gravitation is itself variable with depth. These applications can in many cases be best made by those familiar with the properties in question as measured in the laboratory. The course of earthquake waves, to take an example of interest to the Section of Seismology, is dependent both upon the elastic constants of the earth's materials, and the possible reflection and refraction of waves at the boundaries of internal structural features.

In this connection, the members of this Section could do a service to the other Sections by making clearer the real meaning of some of the physical concepts and physical constants involved in geophysical problems. For instance, much confusion has been caused by the fact that there is more than one kind of "rigidity". The geologist to whom the statement that "the earth has the rigidity of steel" is rather vague may take temporary comfort from the fact that the statement also needs much qualification and explanation to the physicist.[2]

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General Geophysics.—The physics of the earth considered as a unit (the classical "geophysics") is for the most part either covered by other Sections of the Geophysical Union or is customarily considered as a part of geology. Certain phases of geophysics, however, are not thus assignable and may be mentioned here in order that all of the groups of problems of the science may receive attention in this assembly of surveys.

The form and gravitation relations of our suspended spheroid, its magnetic and electrical properties, its properties as a vibrating body, and the physics of its air and water envelopes, are the obvious fields of appropriate Sections. Hypotheses of its origin and the logical deductions therefrom may confidently be left to the geologists, among whose faults that of narrow-mindedness and lack of a broad outlook in time and space have seldom been numbered.[3] Its properties as an absorbing and reflecting body for external radiation are being well handled by the astrophysicists and meteorologists.

The problem of the earth as a body radiating its own heat into space, however, is an example of a problem that may fail of treatment as a unit problem by any one of the above-mentioned groups acting alone. We are dealing not with a solid homogeneous spheroid of uniform surface temperature radiating freely into space, but with a rather heterogeneous body blanketed with several kinds of heat insulators whose composition varies both with depth and with time. Factors in the problem are: the production of heat by shrinkage; the contributions of heat from radioactive sources; the earth's present thermal conductivity and thermal gradient; the effect of varying carbon dioxide, water, ozone, inorganic dust, and clouds, upon the heat loss; and the effects of the possibly very different atmospheres with which the earth has been blanketed in past ages. The temperature at a given time and at a given distance from the center, as for instance at the solid surface of the land, depends upon a complex set of factors, and may well have been periodic in its variations.

The earth's volume and shape may have been similarly variable. In addition to the variation of temperature, already mentioned, the following are among the factors to be considered: the tides in the solid earth (on which extensive experimental work has recently been in progress) and the earth's properties as an elastic body; the viscosity of the earth as a whole, with relation to long-continued forces, and the existing state and method of maintenance of isostatic equilibrium in its surface layer; its breaking strength and form of rupture under forces changing too rapidly to cause flow; and the lag of elastic and viscous responses to changing forces, as in the case of the addition or removal of continental ice sheets.

Limitations of space forbid more than a sketchy outline of the problems set before the Section of Geophysical-chemistry, but it is hoped that the

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outline may have been sufficient to indicate the very fundamental character of those problems.

GEOPHYSICAL LABORATORY,
CARNEGIE INSTITUTION OF WASHINGTON.
June, 1920.

[1] U. S. Geol. Survey, *Prof. Paper* **85C**, 1913 (35).

[2] See Lambert, *Journ. Wash. Acad. Sci.*, **10**, 1920 (122–143).

[3] In this connection it is important that the study of the composition and probable sources of the matter now being received by the earth, in the form of stony and metallic meteorites, be continued and extended.

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BULLETIN OF THE NATIONAL RESEARCH COUNCIL

March, 1922 **Number 17**

SCIENTIFIC PAPERS PRESENTED BEFORE THE AMERICAN GEOPHYSICAL UNION AT ITS SECOND ANNUAL MEETING IN 1921

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These papers were presented at the second annual meeting of the American Geophysical Union held at the National Research Council, Washington, D. C., April 18, 19 and 20, 1921. The names of three of the sections (seismology, volcanology and geophysical chemistry) do not appear in the table of contents, as these meetings were devoted to discussion and no scientific papers were presented.

The American Geophysical Union is the Committee on Geophysics of the National Research Council and is the National Committee for the United States of the International Geodetic and Geophysical Union.

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MEASUREMENT OF GRAVITY AT SEA

A Review

By Lyman J. Briggs

METHODS OF DETERMINING GRAVITY AT SEA

The measurement of the acceleration of gravity over the oceans is a matter of interest to the geodesist in the determination of the figure of the geoid and in investigations relating to isostatic compensation. For the requirements of these problems it is desirable that the probable error of the gravity determinations should not exceed one part in 50,000. At first sight this accuracy does not seem to be unattainable, particularly to those who are familiar with the remarkable work that has been done with invariable pendulums on land stations, where the probable error has been reduced to two or three parts in a million. But when we consider that in measurements at sea the vertical acceleration of the ship is imposed upon the gravitational acceleration which we are trying to measure, the difficulty of the problem becomes apparent. For example, in the case of a ship which rises and falls through a height of a meter during a period of 10 seconds, the average vertical acceleration without regard to sign is about 0.004g, or 200 times the permissible probable error of the measurement. Such vertical accelerations of the ship are not uncommon, although the sea is sometimes so smooth that an index point may be set in grazing contact with the surface of a mercury column with almost laboratory precision.

The oscillations of the sensitive element due to the vertical accelerations of the ship may be controlled by damping, but it is doubtful whether the damped system gives the same result as when vertical accelerations are absent. This question cannot be answered from observations at sea, and necessitates laboratory methods of testing gravity apparatus which will be referred to later.

Virtually all the methods that have actually been used for gravity determinations at sea involve and depend upon observations of the length of a mercurial column supported by gas pressure. The pressure p of the gas may be equated to $\rho g h$ where ρ and h refer to the density and height of the mercury column. Knowing p, ρ and h, the acceleration of gravity g can at once be evaluated. The various methods differ in the manner in which p and h are determined.

Siemens' method: The first actual measurements of the variation of gravity at sea appear to have been made by Sir Wm. Siemens[1] in 1875. He believed that at sea the value of g was diminished by an amount very nearly proportional to the depth of the ocean, and his primary purpose

[1] C. Wm. Siemens. On determining the depth of the sea without the use of a sounding line. *Phil. Trans.*, 167, 1877, 671-692.

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was to develop a sounding apparatus on this principle as an aid to navigation.

His first instrument consisted of a barometer with a large sealed-off air chamber to eliminate the effect of variations in atmospheric pressure (fig. 1). The barometric column included three liquids—mercury, diluted alcohol and juniper oil. The vertical column was expanded into a bulb *b*, at the level where the mercury and alcohol surfaces were in contact, with a second evacuated bulb *d* at the top, which contained the free juniper-oil surface. The readings were made on the position of the alcohol-oil surface *c* in the constricted tube joining the two bulbs. With this device the scale deflection for a given change in *g* was 300 times that of a simple mercurial column.

This instrument proved unsatisfactory and was abandoned in favor of a second "bathometer," which consisted of a steel spring balance of a peculiar type. A vertical steel tube was fitted with reservoirs at top and bottom, the floor of the lower reservoir consisting of a thin corrugated steel diaphragm. This system contained mercury, the free surface of the mercury being in the upper reservoir, which during measurements was open to the atmosphere. The load on the diaphragm was carried by two long steel spiral springs connected to a yoke beneath the diaphragm and suspended from the upper reservoir. The mercury constituted the load on the balance and at the same time served to damp the oscillations through the action of a constriction in the tube just below the upper reservoir. The change in the load due to a change in *g* resulted in a vertical displacement of the yoke and was measured by means of a micrometer screw supported from the lower reservoir. The observations required corrections for temperature and atmospheric buoyancy. The instrument was not checked by testing it at two land stations where the relative value of *g* was accurately known. His results show, however, a remarkable correlation with the depth as obtained by direct soundings, which were made immediately after the bathometer readings. In a series of about 30 observations involving depths up to about 2,500 fathoms, the discrepancy was seldom more than 10 per cent. No corrections were applied for variation in latitude, which ranged from 45° to 49° N.

Hecker's method: The appearance of Helmert's equation for the variation of *g* with latitude, based on land stations, led Hecker[1] to undertake the task of providing data to test its validity for sea stations as well. In 1901 he began an extended series of gravity measurements at sea which eventually included systematic observations in the Atlantic, Pacific and Indian oceans and in the Black Sea.

In using a barometric column for measuring *g*, two procedures are available: (1) the air chamber at the base of the column may be sealed,

[1] For a description of the apparatus employed by Hecker and a summary of his ocean measurements, see Hecker, O., Bestimmung der Schwerkraft auf dem Schwarzen Meere und, an dessen Küste sowie neue Ausgleichung der Schwerkraftmessungen auf dem Atlantischen, Indischen, und Groszen Ozean, *Zentralbur. Internat. Erdmessung*, Veröffentlichungen Berlin, N. F., Nr. 20 (1910).

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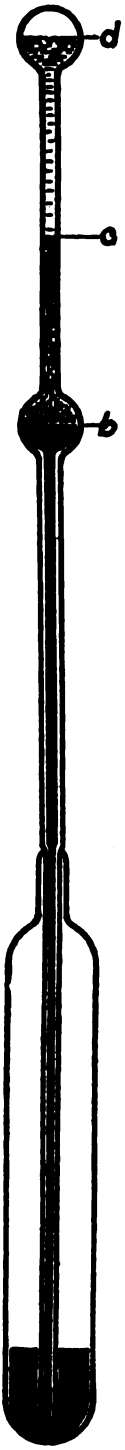

FIG. 1. Siemens' first apparatus.

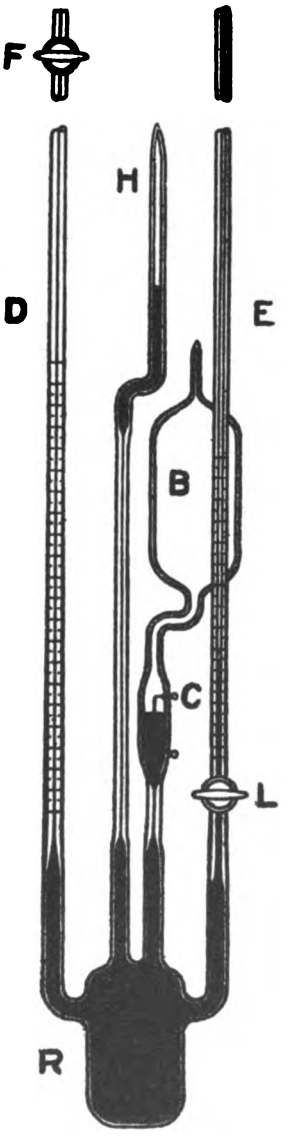

FIG. 2. Duffield's apparatus.

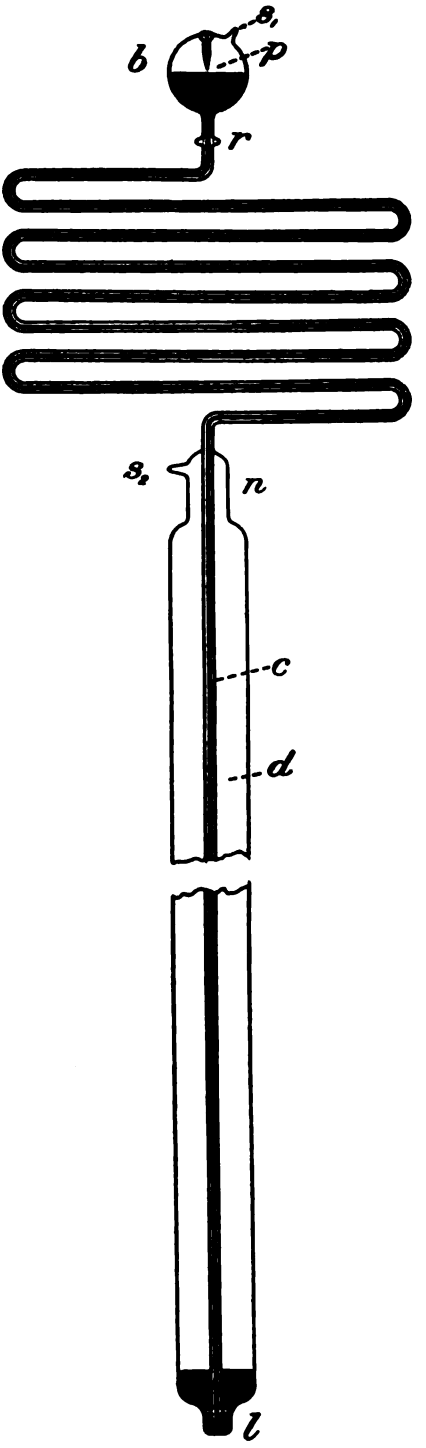

FIG. 3. Briggs' apparatus.

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as in Siemens' first instrument, in which event we eliminate variations in pressure due to atmospheric changes, but are left with an instrument which is very sensitive to temperature changes, as it becomes in effect a gas thermometer; or (2) we may leave the air-chamber open to the atmosphere; in this case the temperature effects are greatly reduced, but it is necessary to measure the air-pressure p by some independent means.

Hecker in his pioneer investigations chose the latter procedure and determined the pressure from boiling-point measurements of water referred to vapor-pressure tables. The vapor-pressure of water increases very rapidly with temperature in the neighborhood of the boiling-point,—approximately one twenty-eighth of an atmosphere per degree. Therefore, in order to determine the pressure to 1 part in 50,000 it is necessary to know the temperature interval from freezing-point to boiling-point with an error not greater than 0°.0006 C.

Hecker used mercury thermometers in his boiling-point determinations. He had no means of checking the fundamental intervals of these thermometers at sea, for this determination depends upon accurate barometric pressure measurements which can be obtained only at land stations where the value of g is known. Consequently any departure of the fundamental interval from that determined at land stations enters directly into the boiling-point determinations at sea as a systematic error. Furthermore, the best of mercurial thermometers exhibit variations in the fundamental interval. For example, Waidner and Dickinson[1] found that the fundamental interval of the primary mercurial standards of the Bureau of Standards varied through a range of 0°.015 C. during a ten-day period, which would correspond to a variation of more than one part in 2,000 in the value of g. The probable error of the fundamental interval determinations in Waidner and Dickinson's measurements under favorable laboratory conditions was ±0°.003 C., which may be taken as a measure of the maximum refinement obtainable in barometer-hypsometer measurements aboard ship; and this corresponds to a probable error in the value of g of more than one part in 10,000.

If hypsometer determinations are to be made, resistance thermometry would be preferable to mercurial thermometry, since the resistance thermometer is more sensitive and shows less variation from day to day in the fundamental interval. The steam point of a resistance thermometer can be readily determined under laboratory conditions to 0°.002 C., but whether this accuracy could be obtained on board ship with the galvanometer on an unstable base is questionable.

In my opinion, the barometer-hypsometer method is not the most promising way of attacking the problem of measuring g at sea, because (1) the method involves two operations; (2) the temperature errors in hypsometry lead to errors in the derived value of g which are ten times as great as those produced by equal temperature errors in a closed system; and (3) the motion of the ship relative to the air produces a change in baro-

[1] *Bull. Bur. Standards*, 3663, Washington, D. C. (1907).

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metric pressure below deck. If this relative motion is unsteady from any cause, as for example variable winds, errors may result unless the barometer and hypsometer are read simultaneously. Duffield (1921) on board a destroyer observed pressure effects of this kind as large as one millibar.

The use of a sensitive aneroid barometer has been proposed as a substitute for hypsometric measurements, but here again a double operation is involved. If a spring system could be devised which would be sufficiently sensitive and reliable to measure pressure to the required degree of accuracy, it would be better to employ it directly as a force balance to measure the change in g than to equate the observed pressure to the observed length of a mercury column, for the double operation serves only to increase the probable error of the final result.

Duffield's method: Duffield[1] in 1914 employed the apparatus shown in figure 2 in some preliminary measurements of g during a voyage from Australia to England. The apparatus, which is of the sealed gas-chamber type, possesses a unique and valuable temperature-compensation feature. A constant volume of air is maintained in the bulb B by keeping the mercury always up to the electrical contact at C. The air in the bulb B is under reduced pressure in order to reduce the length of the apparatus. The barometer tube is bent so that H is vertically above C, the length of the column HC being approximately 20 centimeters. The mercury level is kept at C by raising or lowering the mercury in the index tube D. This operation is effected by slowly exhausting or admitting air through F as required. The index tube D is of fine bore and the value of g is calculated from readings upon the level of the mercury in this tube when contact is made with the pointer at C. The side tube E is used only for the purpose of making initial adjustments, and to permit the apparatus to be used for various ranges of temperature.

The reservoir of mercury R is introduced for the purpose of temperature compensation and when the dimensions of the apparatus are suitably chosen the increased pressure of air in the bulb B due to a given rise of temperature is automatically counterbalanced by the rise of the level H, occasioned by the expulsion of mercury from the reservoir. The compensation is perfect at only one temperature, but for small departures the error is small. At sea the apparatus was immersed in a water bath which was hung by cords from the ceiling of the refrigerator room of the ship, and readings on the index tube were taken through a window in the side.

Duffield's apparatus as reconstructed in Australia was over compensated, an increase in temperature of 1° C. necessitating the removal of a thread of mercury 60 mm. long. In other words, a temperature change of this amount resulted in a change in the reading of the index scale corresponding to the computed change in g in going from the equator to 54° N. Lat. Trouble was also experienced from a break in the capillary

[1] W. G. Duffield. Apparatus for the determination of gravity at sea. *Proc. Roy. Soc. Lond.* (A), 112, 1916, 505-517.

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mercurial column in the barometer tube. Owing to these difficulties actual observations were limited to a series of 25 preliminary measurements in the Indian Ocean from Lat. 0° to 16° N. These results show an average deviation with regard to sign of +0.01 cm./sec.[2] from values computed from Helmert's equation; in other words, a chance distribution of the observations about the line representing Helmert's computed values is indicated. The average deviation of the observations without regard to sign is 0.14 cm./sec.[2]. The anomalies are, however, not known. If we assume that there are no anomalies, this corresponds to an average error of 1.4×10^{-4}. It is interesting to note in this connection that Schuster computes from the dimensions of Duffield's apparatus a maximum error due to pumping of about 3.6×10^{-4} for vertical motions of the ship of one meter amplitude.

In a recent article Duffield[1] has given a brief description of tests made with apparatus other than his own during his voyage to Australia in 1914. This included instruments of the sealed-cistern barometer type constructed by Prof. Hecker and an aneroid barometer supplied by Sir Horace Darwin. No quantitative results are given.

Schuster[2] has contributed a valuable analysis of the effects of forced vibrations which may be imposed on the mercury in gravity apparatus by the vertical acceleration of the ship. This includes a discussion of (1) a single constricted barometer tube, (2) the oscillations in a complex interconnected system of three tubes as in Duffield's apparatus, and (3) the experimental errors in the latter apparatus as affected by the relative dimensions of the various parts. He emphasizes the importance of the condition that the flow of mercury in the barometer tube and contact tube be such that the difference in level is always that of hydrostatic equilibrium. This condition is fulfilled if the cross-sections of the capillaries are equal and the lengths of the capillaries are inversely as the reduced[3] cross-sections of the tubes at the free surfaces of the mercury.

Briggs' method: Briggs[4] employed apparatus similar to that shown diagramatically in figure 3 for gravity observations during a voyage from Sydney to San Francisco in 1914 and again from New York to San Francisco via Panama in 1915. This apparatus is of the closed-barometer

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[1] The investigation of gravity at sea. *Nature*, 106, 1921, 732-734.

[2] Arthur Schuster. On the determination of gravity at sea (Note on Dr. Duffield's paper). *Proc. Roy. Soc. Lond.* (A) 112, 1916, 517-528.

[3] The reduced cross-section a represents the actual cross-section a corrected for the effect of the pressure and volume of the air above the surface of the mercury. Let

V=the original volume of air.

P=the original air pressure.

h=the height of the mercury column equivalent to P.

$$\text{Then } \frac{1}{a_1} = \frac{1}{a} + \frac{h}{V}$$

[4] L. J. Briggs. A new method of measuring the acceleration of gravity at sea. *Proc. Nat. Acad. Sci.* 2, 1916, 399-407.

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type. The mercurial column is contained in the capillary *c* (bore 0.6–0.7 mm.), the lower end of which opens beneath mercury in the bottom of the gas chamber *d*. This capillary is sealed to the wall of the gas-chamber where it passes through the upper end. The upper part of the capillary is bent into a flexible zigzag and ends in the spherical bulb *b* (diameter 2 cm.). The bulb contains a fixed iron point *p* sealed to the inside of the bulb by means of an inserted platinum wire and extending vertically downward, so that the point is approximately at the center of the bulb. The length of the mercurial column is about 74 cm.

The flexible capillary permits a slight vertical movement of the observing bulb with respect to the gas chamber. This movement is determined by a micrometer screw of 1 mm. pitch which controls the motion of a carriage in which the observing bulb is rigidly mounted. The carriage slides on parallel rods mounted on a base which is rigidly cemented to the neck *n* of the gas chamber, so that the position of the bulb relative to the gas chamber is definitely determined by the screw.

The apparatus is protected by a close-fitting metallic jacket, and is kept at a constant temperature in a bath of melting ice. It is necessary to determine only the position of the upper end of the barometric column. The design of the instrument is such that in setting the index in contact with the mercury surface the enclosed gas is automatically reduced to a constant volume; and since the temperature is constant, all measurements are made at constant pressure. The relative value of g at two stations is thus inversely proportional to the observed length of the column at these stations.

The contact of the index point with the mercury surface can be determined either electrically or by direct observation. Both methods were used. In the latter case the fixed point was observed through a glass tube introduced through the ice, the tube containing a low-power lens. The point was illuminated through a similar tube on the opposite side. If the sea was so rough as to cause pumping of the column, the point was so adjusted that it was in contact half the time as nearly as possible. Since the motion of the ship is not strictly periodic, there is considerable uncertainty connected with such settings.

This instrument possesses the following features which experience has shown are desirable in gravity apparatus: (1) The glass part of the apparatus is hermetically sealed and can be made really gas-tight. There are no stop-cocks, ground joints, or mercury seals. (2) It is necessary to make settings only at the upper end of the barometric column. (3) This permits the complete immersion of the apparatus in an ice-bath, which is the most dependable source of constant temperature for use on shipboard. (4) The apparatus is portable, since at room temperatures the pressure is sufficient to fill the observing bulb with mercury.

Gravity determinations which were made in 1914 on board ship in Wellington harbor and Sydney harbor using observations in San Francisco harbor as a base station, and in 1915 in San Francisco harbor using New

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York harbor as a base, show an average departure from pendulum observations of about one part in 50,000. These observations were made under favorable conditions and serve to show the degree of accuracy with which the instruments held their adjustments during the long voyages rather than to provide any indications of the accuracy of the sea observations. In fact, the publication of the sea measurements, which show some rather large anomalies, has been withheld in the hope that apparatus similar to that described in the last section of this paper might be available to determine the errors of the instruments under oscillations approximating sea conditions.

CORRECTIONS FOR THE COURSE AND SPEED OF THE SHIP

Eötvös[1] has shown the necessity of applying a correction for the easterly or westerly motion of the ship, due to the fact that the ship's motion modifies the angular velocity of the apparatus about the earth's axis. The centrifugal force acting on the mercurial column when on board a ship moving east or west is therefore not the same as when the ship is at rest or moving north or south. The correction may be as great as 1 part in 10,000, but can be accurately computed if the course, speed, and approximate latitude of the ship are known. Duffield (1921) observed a change equivalent to 0.1 millibar when the course was altered from east to west when steaming at 22 knots, which corresponds to an apparent change of 1 part in 10,000 in g. He does not state where his experiments were made. For Lat. 55°, which represents approximately the mean latitude of the North Sea, the computed change is about 0.19 cm./sec.^{2}, or 2 parts in 10,000 in the value of g.

LABORATORY TESTING OF GRAVITY APPARATUS

There seems to be no practical way of determining the accuracy of gravity measurements directly from sea observations. With a ship at one's command, repeated traverses could be made of the same sea station under varying sea and weather conditions; but while this would provide a measure of the accidental errors, it would tell us nothing regarding systematic errors, for the exact value of g at the station would not be known. The value of g in a long, narrow bay could be closely approximated from pendulum observations on both shores. To satisfy other requirements the bay would have to be sufficiently open and windswept to represent the conditions prevailing in a moderate sea. Such a test seems precluded without the enlistment of government aid.

We can, however, simulate sea conditions at a land station where g is accurately known and I wish to emphasize the importance of such tests for all gravity apparatus. Suppose we construct a platform capable of independent reciprocating horizontal translations in two directions at right angles, corresponding in period to the roll and pitch of the ship. Let us mount upon this platform a second one arranged for vertical oscillations,

[1] See Helmert, *loc. cit.*

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large enough to carry the apparatus and the observer. All the reciprocating motions are to be capable of a continuous change in amplitude if desired in order to secure the conditions which arise when the period of the ship differs from that impressed by the waves. We have omitted the motions corresponding to the angular motions of the deck, for structural reasons; for these angular motions would only increase the rotation of the apparatus in its gimbals, and there will always be sufficient movement of the gimbals arising from the horizontal accelerations to simulate disturbances due to friction. With this apparatus it will be possible to investigate the effects of horizontal and vertical accelerations, singly and combined, under conditions where g is accurately known and thus obtain a measure of the accidental and systematic errors of the method. Independent rolling and pitching oscillations are probably not required for gravity apparatus, but the equipment proposed has other useful applications, as for example in testing gyroscopic compasses and gyroscopic stabilizers, in which both rolling and pitching accelerations should be included. Plans for such an equipment are now being prepared, and it is hoped that arrangements can soon be made for its construction and installation at the Bureau of Standards, where it will be available for testing all gravity apparatus.

Bureau of Standards,
Washington, D. C.

ISOSTASY

By John F. Hayford

I assume that I am expected to bring forward whatever ideas will, in my opinion, help most at the present time in the development of a study of isostasy by stimulating further thinking along that line. From among the many topics which might be treated, I am selecting three:

(1) I shall make some remarks on the recent paper entitled "The Chemistry of the Earth's Crust," by H. S. Washington.

(2) I shall try to emphasize the desirability of an intensive study of two small areas by observations of gravity and deflections of the vertical.

(3) I shall offer some considerations that lead me to believe that the undertow involved in isostatic readjustment is above, rather than below, the depth of compensation.

CHEMISTRY OF THE EARTH'S CRUST

Dr. Washington, in his paper entitled "The Chemistry of the Earth's Crust," [1] has set forth a piece of research of much importance to those who are studying isostasy. He has set forth the evidence derived from studies of the densities of igneous rocks. These densities are determined from chemical analyses. In the latter part of the paper he sets forth the correlation which is observable between the density of igneous rocks, on

[1] *Journal of the Franklin Institute*, 190, December, 1920, 757-815.

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the one hand, and, on the other hand, the elevation of that part of the earth's surface under which the rocks lie.

The evidence given in the paper seems to be conclusive in its general features on three points, namely:

(1) That igneous rocks under the oceans are denser than those under the continents;

(2) That igneous rocks under the various continents are less dense the greater the mean elevation of the continent; and

(3) That igneous rocks under different parts of any one continent are less dense the higher is that part of the continent.

All three of these conclusions are in accord with the theory of isostasy and, in Dr. Washington's words, constitute "almost a conclusive proof of the general validity of the theory of isostasy."

Dr. Washington seems to interpret the relations pointed out as being due to original, or early, segregation of the material. I do not question this interpretation so far as (1) is concerned. The relative positions of the oceans and continents are permanent or semi-permanent. It may well be that the oceans are now in their present position because material of such a nature as to form dense rocks was placed early in the positions now occupied by the oceans.

The same interpretation may, however, be questioned, in part, in so far as (2) and (3) are concerned. Are the differences in densities between the different continents referred to in (2) and between different parts of any one continent referred to in (3) due to original or early segregation? Or are these differences due, in part at least, to some response of the material to a change of pressure in such a manner as to bring about a change of density? The continents probably have not had the same relative elevations throughout geologic time as they now have. Certainly, the different parts of any one continent have not, in general, the relative elevations now that they had at various times during the geologic history of the continents. For example, the Appalachian region, referred to by Dr. Washington, in the eastern part of the United States, is now much lower than Utah, Colorado, and Nevada, and the density of the material, as measured by him, is considerably greater under the Appalachian region than under the states named. There was, however, a time during the geologic history of the North American continent when the Utah-Colorado-Nevada region was much lower than the Appalachian region was at that time. Have the relative densities in the two regions changed between that period and the present?

This comment on Dr. Washington's paper is not intended at all as a criticism; it is intended to supplement the paper and to stimulate further thought based on it. All who are interested in isostasy should be very keen to follow the further develpoments along the line indicated by Dr. Washington's paper. I understand that he, himself, will develop the evidence much more fully. The more complete evidence should be examined very carefully, with a view to determining the bearing of this evidence on

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any theories which may be held in regard to isostasy and the isostatic readjustment.

PROPOSED INTENSIVE STUDY OF SMALL AREAS

We shall take a short time to consider the possible benefits which would follow from an intensive study of two small areas, let us say about 100 miles square, one on rather flat country, such as Louisiana, and another in hilly or mountainous country. The intensive study would be based on closely spaced stations of two kinds, stations at which deflections of the vertical are determined and gravity stations. Let us suppose that observations of these two kinds were made in each of two such areas and then that, by the proper office methods and by the combination of the two kinds of observations, the distribution of the densities beneath each of the two areas was determined with as great accuracy as is possible. What benefits would follow from two such studies? Briefly, I believe that the benefits would be as indicated in the four paragraphs which follow:

1. The studies would bring out the actual advantages and limitations of this line of attack on the problem of determining the distribution of densities beneath the earth's surface. The relative strength or weakness of this line of attack, as compared with the usual line of attack, is not now well known. The usual line of attack is to use deflections of the vertical stations or gravity stations which are widely distributed somewhat uniformly over a very large area.

2. The studies would probably furnish a considerable amount of evidence on the point which has been ably brought out by Dr. William Bowie that the small anomalies in gravity and in deflections of the vertical which remain after correcting for topography and isostatic compensation are closely related in many regions, if not as a rule, to the surface geology of those regions. It is important that the extent to which this is true should be determined. There seems to be no doubt that it is true, in a general way, for large areas. The question is, to what extent is it true for small areas?

3. The studies would give valuable indirect evidence as to the extent to which the present conclusions from the evidence now available are vitiated by local effects which are at present unavoidably assumed, for want of more exact information, to extend half way to the next station, so to speak.

4. The two intensive studies would help to determine whether oil and salt may be located by geodetic measurements. This suggestion has been made at various times by Dr. David White, Chief Geologist of the U. S. Geological Survey. It is important to know whether gravity stations and deflections of the vertical may be used as a divining rod for that purpose with sufficient accuracy. If the accuracy of such a divining rod is so low that its indications are likely to be misleading, then it is not feasible to try to use the observations in this way. On the other hand, if two such intensive studies as are indicated here show that sufficient accuracy is

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possible, then certainly the method should be used, in combination possibly with other methods. The two intensive studies might possibly be made in regions in which salt or oil are believed to exist, or are known to exist, in large quantities.

The suggestion that one study should be in rather flat country and the other in rather hilly country is based on two considerations. In very flat country the conclusions reached will be vitiated to a much smaller extent by an error in the assumed surface density of the material than in rough country. On the other hand, in hilly or mountainous country the depth at which any material of abnormal density lies may be determined with greater accuracy than in flat country.

DEPTH OF UNDERTOW

Let us now turn to the question, is the undertow involved in isostatic readjustment above or below the depth of compensation?

Assume that, at some time in the remote geologic past, the North American continent and its various major parts have been almost completely compensated in the isostatic sense. Assume that, in later geologic past time and up to the present time, there have been large amounts of erosion from large portions of the continent and corresponding large amounts of deposition in other parts. Assume that in that period and up to the present, readjustment toward isostatic conditions has been in progress by horizontal transfer of material from beneath the regions of deposition towards the regions of erosion.

It is reasonably certain that, on the whole, these three assumptions are true. The question on which it is desired to concentrate attention is, has the horizontal transfer taken place below or above the depth of compensation?

It is important to secure the correct conclusion on this point, whatever it is, because the apparent correlation of geodetic and geologic evidence, or the apparent contradictions between two lines of evidence, probably depend somewhat intimately upon the conclusion reached. I believe that the horizontal transfer has taken place above the depth of compensation, say within 100 kilometers of the surface, rather than below that depth. I propose to state, very briefly, some of the lines of thought that have led me to that conclusion.

If it is assumed that, under an area of deposition, the material down to the depth of compensation all sinks under the added load and that the horizontal transfer of material occurs below that depth, the case is similar to that of an ice floe. Under each elevation on the upper surface, in this case, there must develop a much larger bump on the lower surface of the floating mass. The conception is that of a crust floating on a relatively plastic stratum. The level of compensation, in this case, is at the lower side of the floating crust. As in this case there must be extensions of the crust downward, below the mountains, the depth of compensation will be variable, being great under high areas and small under low areas. The

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geodetic evidence, as far as I have been able to examine it, does not seem to be conclusive that there is any such relation between the depth of compensation and the elevation of the surface. This leads me to be skeptical of such theory, which involves a horizontal flow limited mainly to those portions of the earth that are below the depth of compensation.

In general, I am skeptical of any explanations of isostatic readjustment, or of other phenomena in the earth, which involve a relatively plastic stratum in contrast to more rigid material above. In each of the cases in which I have been able to follow the mechanics of the problem to my own satisfaction, I have not been convinced that the resort to the device of introducing a plastic layer into the concept is necessary. So, in the problem now under consideration, which is that of the isostatic readjustment, I do not find it necessary to assume any stratum to be more plastic than the one above, in order to harmonize the observed facts of various kinds.

There is abundant geological evidence of horizontal stresses and strains in the earth's crust. This evidence seems to me to be conclusive. The geologic evidence seems to me to indicate a horizontal transfer of material during isostatic readjustment relatively near the surface, rather than at great depths. If the horizontal transfer involved in the undertow were in a plastic stratum more than 100 kilometers below the surface, certainly the horizontal stresses set up in the surface material would be much less than if the same transfer occurred in less plastic material nearer the surface.

In attempting to determine the mechanics of the isostatic readjustment which apparently takes place when great loads are removed from a region of erosion and equally great loads are added to other regions as deposited material, it is extremely important to keep in mind that material deforms under relatively small differences in the two principal stresses. A very large increase in both the principal stresses is necessary in order to produce deformation if the increases are equal. In an elementary cube of the material, let p_2 be the pressure on the upper and lower faces of the cube. Let p_1 be the pressure on the side faces of the cube. If $p_2=p_1$, the material is under isostatic conditions. Under these conditions both p_2 and p_1 may be increased very largely before appreciable compression is produced in such material as constitutes the earth's crust. On the other hand, if p_2 is increased without changing p_1, then deformation of the cube will be produced for a relatively small difference p_2-p_1, corresponding to an added load of a few thousand feet only of material. The cube will be deformed in the sense in which the vertical dimension is decreased and the horizontal dimensions increased. Consider the movements which will take place if the many elementary cubes under a large loaded area are so distorted. Evidently the motions of the material under the margins of such a load will have a horizontal component. This line of thought, followed through to its logical conclusions, and made more definite by careful analysis, will indicate that the horizontal transfer of material occurs largely at moderate depths, certainly at less than 100 kilometers as a rule.

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I am perfectly aware that the presentation of the considerations set forth in the last few paragraphs has been too brief for clearness or conclusiveness. The paragraphs have been written as suggestions rather than as demonstrations. They indicate lines of thought which should be followed up carefully if one wishes to reach true conclusions.

I desire to reiterate my opinion,[1] based on such thought as I have been able to give to the subject, that the undertow involved in isostatic readjustment is above the depth of compensation.

THE EARTH-TIDE EXPERIMENT

By Henry G. Gale

I understood Professor Hayford to say that he did not believe that a fluid layer exists beneath the solid crust of the earth. The same conclusion may be drawn from the earth tide experiment which was conducted on the grounds of Yerkes Observatory by Professor Michelson and myself. It seems pretty certain that the earth tides are the same as they would be if the earth were a highly elastic homogeneous solid, both with respect to the phase and amplitude of the earth tides.

The experiment was entirely successful from a physicist's standpoint. The interferometers gave very little trouble. One of them did not require readjustment during the entire year. Two were readjusted to change the width of the fringes, and on one interferometer it was necessary to resilver one of the mirrors. As a source of light we used commercial alternating Cooper-Hewitt lamps, and they proved to be entirely satisfactory. The only serious interruptions were caused by breaks in the electric service due to storms, and occasional short shut-downs by the electric light company which supplied the current. The experiment at Yerkes Observatory was continued for just one year. This is probably long enough to give values of the semi-diurnal and diurnal tides, accurate to a few tenths of one percent. For tides of longer period the experiment should be continued for, say, five years, although possibly three years would be long enough.

The experiment is now being repeated on the grounds of the California Institute of Technology at Pasadena, California. One additional station should be installed, preferably on an island in the Pacific, far from the continental borders. If the three stations should give results in agreement on both the phase and amplitude of the earth tides, I should feel that the problem had been solved. If the three were not in agreement, at least one-half dozen additional stations would be desirable. They should be well scattered in latitude, and with reference to tidal coasts.

The cost of installing a station is not excessive, and one man can easily keep a station in operation and reduce the observations. It would probably be worth while to look for a correlation between the slight changes of

[1] As early as 1911 I had reached the above conclusion, as indicated by one of the diagrams in an article published in *Science*, 23, No. 841, 199-208, Feb. 10, 1911, entitled "The relations of isostasy to geodesy, geophysics and geology."

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level often shown by the apparatus and the approach or passage of the intense barometric lows and highs of large area. It would certainly be worth while to install a specially designed apparatus, similar to that used for the earth tides, to detect and measure the rate of tilting in the surface layers of the earth's strata at especially favorable places. A relation between such rates of tilting and earthquakes might be detected.

THE EÖTVÖS BALANCE

By W. D. Lambert

There is one instrument of use in the study of terrestrial gravity which has not yet been employed in the western hemisphere, though it has to a limited extent in Europe. This instrument is the Eötvös balance. It should be tried, I believe, in making the proposed minute investigation of gravity in a level region of limited extent.[1] To judge by accounts of work done with the balance in Europe it would certainly supplement the pendulum advantageously in the proposed gravity survey and might largely supersede it. This does not by any means signify, however, that the balance is always and everywhere a substitute for the pendulum. This is not the occasion for an exposition of the principles of the instrument, but it may be said that the Eötvös balance connects the results at adjacent points in a limited region with one another in a way that the pendulum cannot well do.

In Europe they evidently believe in its possibilities as an indicator of the existence and location of concealed irregularities and discontinuities in density. Some of these discontinuities may mean strata of geological or commercial interest. At least three attempts have been or are being made to locate such strata by the use of the balance (1) by Dr. Schumann to locate lignite deposits in Austria,[2] (2) by Professor Schweydar for geological purposes in the region about Hamburg, Germany,[3] and (3) an attempt to locate salt deposits in Poland.[4] It will be of interest to know how successful these attempts prove to be.

The Eötvös balance determines certain second derivatives of the gravity potential function. It does not, however, determine the second derivative in the vertical direction. This quantity has to be determined theoretically. This is the most serious deficiency of the instrument and explains why it is of comparatively little use in rough country. Attempts are being made by Berroth, Helmert's assistant, in his last researches on gravity, to devise a means of determining experimentally the second derivative in the vertical direction.[5]

[1] See p. 13 of this bulletin.

[2] *Akademie der Wissenschaften in Wien:* math. phys. Klasse. Sitzung vom 8 Janner, 1920. Reported in the *Akademische Anzeiger*, Nr. 1.

[3] "Rapport sur les Travaux du Bureau Central de l'Association Geodésique Internationale en 1920," p. 4.

[4] I have seen nothing in print about this third attempt. I have word of it personally from the man proposing to make the observations. [Added in proof: This attempt has not yet been made on account of the lack of instrument.]

[5] Same reference as in second preceding footnote.

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THE PROBLEM OF THE EARTH TIDES

By W. D. Lambert

There are two methods of attacking the problem of the elastic properties of the earth, (1) the study of the seismological evidence, on which I shall not touch at all, and (2) the study of earth tides. Even after the best available observational evidence from the earth tides has been obtained, a good deal of hypothesis and interpretation is required before we can say: "The elastic constants of the earth are thus and so." It is not, however, of this that I wish to speak, but rather of the problem of obtaining the true values of the earth tides. This subject is connected with several other geophysical questions and this paper, therefore, falls naturally into three divisions: (1) Earth tides and the long-period oceanic tides; (2) earth tides and the short-period oceanic tides; (3) earth tides and the variation of latitude.

EARTH TIDES AND THE LONG-PERIOD OCEANIC TIDES

The first quantitative evaluation of the earth tides and hence of the elastic properties of the earth came from a discussion of the so-called long-period oceanic tides. The suggestion which initiated the work appears to have come from Lord Kelvin and the method and results are given in Thomson and Tait's "Natural Philosophy,"[1] but the actual discussion of the observations was made by Darwin.[2]

The discussion is based on the assumption that the long-period oceanic tides for an ocean on a perfectly rigid globe may be calculated on the equilibrium theory. This means that it is assumed that the disturbance of equilibrium caused by the tide-producing forces of long period can travel so rapidly through the water and the forces themselves change so slowly that the ocean has time to adjust itself to the forces and that at any given instant the surface of the ocean forms an equipotential surface for the instantaneous field of force.[3] The observed oceanic tide would be the difference between the oceanic tide for a rigid body and the earth tide, and when the first two are known the earth tide may be inferred. From 33 years of observation on both the monthly and the fortnightly tides at 14 different ports Darwin deduced that the observed tides were about two-thirds as large as they would be on a perfectly rigid globe. The earth tide corresponding to the other third implies an effective rigidity of the earth about equal to that of steel.[4] Later methods of attacking the

[1] Second Edition (1883), § 848.

[2] G. H. Darwin: "Scientific Papers," I, 340. This contains a reproduction of the passage in Thomson and Tait with some changes of notation and unimportant omissions.

[3] This assumption is very evidently incorrect as regards the diurnal and semi-diurnal tides. It was supposed to be at least approximately true for the monthly and fortnightly tides.

[4] The tides at Indian ports, which are more consistent with one another than the others, gave a much higher rigidity.

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problem have given results somewhat similar, though in general tending towards somewhat higher values of the rigidity.

Only a few years passed before this result was questioned because of its dependence on the equilibrium theory, and Darwin himself, apparently, was the first to question it.[1] In treating the problem of tides on a globe covered with water—a problem first formulated by Laplace—he discovered solutions which for depths anything like these of our actual oceans gave tidal oscillations of perhaps half the amount deduced from the equilibrium theory. He concludes his article by saying: "Thus it does not seem likely that it will ever be possible to evaluate the effective rigidity of the earth by means of tidal observation." The mathematical treatment of the problem has since been developed by Hough[2] and Goldsborough.[3] The latter has extended the treatment to include basins bounded by two parallels of latitude, a polar basin or one covering the entire globe being special cases. The general result is that for oceanic depths such as we know the monthly and fortnightly tides in such basins differ considerably from what the equilibrium theory gives, being in general considerably smaller.

These results are decidedly puzzling when compared with observation, for the observed tides would then be larger than the computed tides of Darwin, Hough and Goldsborough instead of being smaller by an amount representing the yielding of the earth to the tide-producing forces. Darwin's solution was re-examined critically by the late Lord Rayleigh.[4] He reaches the conclusion that the solution is a very special one that applies, of course, to the ideal water-covered globe postulated, but which has little relation to our actual oceans, interrupted as they are by continental barriers. He says: "If this conclusion be admitted, the theoretical fortnightly tide will not differ materially from its equilibrium value, and Darwin's former calculation as to the earth's rigidity will regain its significance." After a word of caution about possible exceptional conditions he concludes: "In any case I think that observations and reductions of the fortnightly tide should be pursued. Observation is competent to determine not merely the general magnitude of the tide but the law as dependent upon latitude and longitude. Should the observed law conform to that of the equilibrium theory, it would go a long way to verify *à posteriori* the applicability of this theory to the circumstances of the case."

Rayleigh's belief in the legitimacy of calculating the fortnightly tide—and *à fortiori* the monthly tide—from the equilibrium is supported by the opinion of Love[5] and there is still another reason for accepting this idea,

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[1] *Proceedings of the Royal Society of London*, 40 (1886), 337, or "Scientific Papers," I, 366.

[2] *Philosophical Transactions of the Royal Society of London*, 189, 1897, 201, and 191, 1898, 139. Some account of Hough's work is given in Darwin's article on "Tides" in the eleventh edition of the Encyclopædia Britannica, parts of which are given also in Darwin's "Scientific Papers," I, 347.

[3] *Proceedings of the London Mathematical Society*, Vol. for 1914-15, 31 and 207.

[4] *London, Edinburgh and Dublin Philosophical Magazine*, 5, 1903, 136.

[5] "Some Problems in Geodynamics" (Cambridge, England, 1911), 51.

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namely, the effect of friction. Hough[1] evaluates the modulus of decay under friction for various types of oscillation. The modulus of decay is a *time* of the same order of magnitude as the period of an oscillation that is slow enough to conform approximately to the equilibrium law. For oscillations most nearly corresponding to the long-period tides and with the laboratory value of the coefficient of viscosity of water he found moduli of the order of magnitude of ten years. But this use of the laboratory value of the viscosity seems to be fallacious. The laboratory value applies to the so-called laminar motion, while the motion in the actual ocean is turbulent. When we call the motion turbulent, we say in effect that we do not understand it very well; but it is known that if we attempt to represent turbulent fluid motion by equations of the same form as are used for laminar motion, then the coefficient of viscosity in the latter, which is the laboratory coefficient, must be replaced by a coefficient of virtual viscosity many times greater. Ekman found for water that the coefficient of virtual viscosity was 15,500 times greater; for air, Taylor found the ratio of the virtual viscosity to the laboratory value to be between 6,000 and 50,000.[2] It is not to be supposed that any one ratio of virtual coefficient to laboratory coefficient would apply under all conditions, but if any such virtual coefficient as is here suggested were used instead of the laboratory value, Hough's modulus of decay would be greatly reduced and the equilibrium theory would apply to tides of comparatively short period, even apart from the effect of continental barriers.

It seems to me, then, that it is pretty safe to assume that the monthly and fortnightly tides conform quite closely to the equilibrium theory and that it would be well worth while to resume the study of these tides for the light that they may throw on the rigidity of the earth. The only discussion of the observations since Darwin's original one is due to Schweydar,[3] in which are discussed observations at 43 ports covering 194 years. There must be available among all the harmonic analyses of tides that have been made since that time a great deal of material still unutilized.

In regard to the utilization of this material and the procurement of new material there are three suggestions I should like to make.

First: In securing the observations care should be taken that the tide gauge has a firm foundation. Tide gauges are frequently located on docks supported by piles, or on made ground. If the cost could be afforded, it would be desirable to place them, if necessary, at some little distance from the water in order to get a good foundation, and to connect the gauge with the water by a large pipe. Incidentally, if a firm foundation

[1] *Proceedings of the London Mathematical Society*, 28, 1896, 264.

[2] These values are taken from a paper by McEwen: Ocean Temperatures, their relation to Solar Radiation and Oceanic Circulation; miscellaneous Studies of Agriculture, Biology, Semicentennial Publications of the University of California. Other examples of very wide differences between laboratory and field values are also given by McEwen. The work of Ekman and Taylor is found respectively in the *Arkiv for Matematik, Astronomi och Fysik* 2, 1905, 1. and in the *Philosophical Transactions of the Royal Society of London*, 215, Ser. A, 1915, 1.

[3] *Beiträge zur Geophysik*, 9, 1908, 64.

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were assured, the tide records would be valuable in studying the secular rising and sinking of the coast. Too many long series of tidal observations that would have been valuable for this purpose in the past have been rendered useless for lack of connection with well-established permanent marks. Schweydar deduced from his discussion of the tides an effective rigidity of the earth rather less than that of steel and suggests that the discrepancy between this result and the higher rigidity obtained from the variation of latitude may be due to a plastic stratum beneath the crust. He seems to have abandoned later his belief in this plastic stratum. Perhaps such a stratum exists, after all, but it may consist simply of the alluvial ground, mud or made land on which some of the tide gauges are situated.

Second: In reducing a year's tidal observations at a place to obtain the long-period tides it is found that the tides are much entangled with one another. To separate them Darwin gives a rather tedious process of successive approximations. It is possible to dispense with these repetitions at the price of a rather heavy piece of preliminary computation that is done once for all series of a given length, such as a year. If many long-period tides are to be reduced, it would be well worth while to do this preliminary work. Furthermore, Harris has suggested that if four consecutive years be taken together, the several long-period tides will separate satisfactorily from one another and the computation will be simpler.

Third: In the final discussion we seek to obtain the earth tides from the difference between the theoretical tides on a rigid globe and the observed tides. Now, even accepting the comparatively simple equilibrium theory, which we are at present supposing to be adequate, the tides on a rigid globe have not been evaluated as accurately as could be wished. The difficulties are the attraction of the water on itself and the presence of the continents. Either difficulty by itself is readily overcome. If there were no continents and the globe were covered with water, a simple factor derived from the fundamental principles of spherical harmonics would take care of the self-attraction of the water. On the other hand, if we disregard the self-attraction of the water, the influence of the continents can be allowed for as Darwin and Turner[1] have done in following Sir William Thomson's (Lord Kelvin's) suggestion.

It is the combination of the two circumstances, neither of which is troublesome by itself, that makes trouble, for the resultant of the two cannot be had by simply superposing two corrections. The total effect cannot be very large, but the modulus of rigidity is rather sensitive to changes in the ratio of the observed tide to the theoretical tide, especially if this ratio be near to unity, so that it seems perhaps quite possible that the modulus of rigidity may be changed as much as thirty or forty percent by the application of the corrections above mentioned.

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[1] *Proceedings of the Royal Society of London*, 40, 1886, 303, or Darwin's "Scientific Papers," I, 328.

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The evaluation of this correction of the combined effect of the continents and the self-attraction of the water seems to me a problem worthy of study. No advance seems to have been made since Poincaré's paper,[1] in which he works out a solution very elegant in conception, but one which, as Poincaré himself says, would lead to calculations far too complicated to be practicable even if the shore line of the continents were arbitrarily simplified into a rude approximation to its actual form. I believe, however, that it may be possible to solve the problem numerically by a laborious process of successive approximations, involving the preparation of maps showing the equilibrium tide corrected for the continents alone, and the reading of these maps for many points on the earth, much as contour maps are read to obtain the deflections of the vertical. The labor would be more than an individual investigator would care to undertake, but might well be within the means of an institution. Perhaps the theory of integral equations in its recent developments might afford means of lightening the labor.

EARTH TIDES AND THE SHORT-PERIOD OCEANIC TIDES

In discussing observations of earth tides as a means for obtaining the elastic constants of the earth—observations made either with horizontal pendulums or with Michelson's tube and interferometer—it is important to have a knowledge of the oceanic tides. This statement applies to tides of all periods, but these remarks apply more particularly to tides of short period, i. e., to the diurnal and semidiurnal tides. Tides of longer period have just been discussed.

The shifting mass of tidal water exerts a direct gravitational effect on the horizontal pendulum or on the liquid in the tube, and the direct effect is reinforced by the tilting of the earth's crust under the shifting load of tidal water. The periods of these effects are precisely the periods of the tide-producing forces; hence it is impossible to make an adequate estimate of the yielding to the tidal forces of the solid earth as a whole until the direct and indirect effects of the oceanic tides have been allowed for.

Probably the most satisfactory determination of the earth tides is that of Michelson and Gale,[2] and it is noteworthy that their observations were made at Williams Bay, Wisconsin, which is some 800 miles distance from the ocean. The yielding of the earth deduced from the north-and-south displacements is nearly the same as that deduced from the east-and-west ones and the yielding deduced from the diurnal declinational tide, O_1, is nearly the same as deduced from the principal semidiurnal tide, M_2.

This satisfactory state of affairs no longer obtains with some of the observations taken elsewhere with the horizontal pendulum. Hecker's

[1] *Journal de Mathématiques Pures et Appliquées*, 2, 1896, 57.

[2] *Journal of Geology*, 22, 1914, or the identical article in the *Astrophysical Journal* for March, 1914. An important correction is given in *Science*, 50, 1919, 327. Definitive results will be found in the *Astrophysical Journal* for December, 1919.

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results at Potsdam,[1] which seemed to show a greater yielding of the earth in the meridian than in the prime vertical, have been a standing puzzle; attempts to explain this peculiarity as due to the rotation of the earth have been unsatisfactory.[2]

More recent observations by Schweydar with horizontal pendulums at Freiberg in Saxony[3] show anomalies also. Perhaps these anomalies are due to the inferior accuracy of the horizontal pendulum as compared with Michelson and Gale's apparatus, but it seems to me probable that the uneliminated effects of the oceanic tides may also play a part.[4] This effect has never been calculated, so far as I know, and has been assumed to be so small as to be practically negligible, but, as we shall shortly see, there are reasons for questioning this assumption.

The only serious attempt to allow for the oceanic tides, so far as I know, is due to Prof. Shida[5] of Kyoto University, Japan. He observed with horizontal pendulums for a year at Kamigamo Geophysical Observatory, near Kyoto. In Japan it is, of course, impossible to get far from tide water, and though the tides in the surrounding waters are not particularly large, but rather the contrary, still considerable effect is to be looked for. Harris's cotidal maps[6] were used for the M_2 component. They are based on actual observation for the coast, but necessarily on theory and inference for the open sea. For the O_1 component special maps were drawn from the somewhat meager data available. From the maps the gravitational effects of the tidal water was read off just as the topographic deflection of the vertical may be read. The effect due to the yielding of the earth's crust was also computed on the most plausible assumptions practicable. The actual computation is not unlike that of the deflection of the vertical; the result comes out that the deflection due to the tilting under the tidal load is about twice the direct gravitational pull of the load itself, and the two corrections combined were of the same order of magnitude as the earth tides proper. For example, the observed O_1 tide on the pendulum swinging northwest–southeast came out

$$+0''.00525 \cos t + 0''.00059 \sin t$$

while the total deflection in the same direction due to the ocean tides was computed as

$$+0''.00410 \cos t - 0''.00250 \sin t$$

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[1] "Beobachtungen an Horizontalpendeln über die Deformation des Erdkörpers unter dem Einflusz von Sonne und Mond," Veröffentlichungen des Konigl. Preusszischen Geodätischen Institutes n. f. no. 32, Berlin, 1907, and Heft 2, n. f. no. 49, Berlin, 1911.

[2] See Love: "Problems in Geodynamics" (Cambridge, England, 1911), 75.

[3] "Bericht über die Tätigkeit des Zentralbureaus der Internationalen Erdmessung im Jahre 1920," 6.

[4] Orloff's observations at Dorpat (reported in *Astronomische Nachrichten*, 186, 1910, 81) show a peculiarity similar to Hecker's but to a less degree. Dorpat is farther removed than Potsdam from the influence of the large tides in the Atlantic.

[5] "Memoirs of the College of Science and Engineering," Kyoto Imperial University, IV, no. 1 (Nov., 1912).

[6] Manual of Tides. Part IV B (Report of the U. S. Coast and Geodetic Survey for 1904, appendix 5).

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where t is the hour angle of the fictitious O_1 tide-producing body of the harmonic analysis. Evidently any inference drawn from the uncorrected earth tides would be quite wide of the mark. The computation was extended to a distance of 40° of great circle (nearly 2,800 statute miles) from the station. This was considered sufficient in view of the meagerness of the tidal data and the approximate nature of the work, but it should be remarked that the zone between 30° and 40° gave in some cases a result equal to more than one-tenth of the whole correction, suggesting the desirability of extending the calculation to even greater distances.

When we consider the great areas of ocean that lie within 40° of any one of the European horizontal-pendulum stations, it seems rash to assume without careful calculation that we may neglect the effects of the oceanic tides on the observed earth tides, and it may even appear desirable to see whether Michelson and Gale's result may not be susceptible of improvement by applying the correction for oceanic tides.

The primary difficulty with calculations of this sort is our lack of knowledge of tides in the open sea. We have Harris's cotidal lines, and it may be said that when these were used for reducing the Kyoto observations the results obtained seem quite satisfactory, thus verifying to a certain extent the theories on which the lines were based. But at best this is theory rather than observation, and Harris himself was as keenly aware as anyone else of the incompleteness of his work and the necessity of verifying it by observation.

The direct observation of tides at sea is a problem beset with difficulties. To observe tides by means of soundings repeated every hour or so at the same point seems impracticable on account of the great depth to be sounded, rendering an accuracy of a foot or less impracticable, and on account of the difficulty of recovering the same point. Pressure gauges in one form or another have been suggested, but the instrument that will sustain the load of a thousand fathoms of water and at the same time be sensitive to variations in that load of a foot or so has not yet been devised.[1]

It has occurred to me, however, that the question of tidal oscillations at sea could be approached somewhat differently, namely, by a study of the horizontal oscillations, that is, the tidal currents. In the open sea these tidal currents would, of course, be small, but not always too small to be detected and studied. Given a good knowledge of the tidal currents, the tidal rise and fall could be inferred with fair certainty. The relatively large tidal currents are to be looked for near the nodal lines of the stationary tidal oscillations, and Harris's theory will indicate plausible places in which to look for such nodal lines.

What has chiefly impressed me with the possibility of measuring tidal currents at sea was the reduction that I made for the late Dr. Harris of

[1] A recording tide gauge for work at sea invented by M. Favé, a French hydrographic engineer, that is said to have given good results at Dover, England, and in the Thames Estuary, is mentioned in the *Observatory*, 43, Aug., 1920, 279.

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observations taken some thirty-five years ago by Lieut. Pillsbury,[1] as he was then, later Rear Admiral Pillsbury. They were not made with the study of tidal currents chiefly in view, but for the exploration of the Gulf Stream. Dr. Harris had them worked over again by more modern methods to see what information about tidal currents could be extracted.[2]

The series were all short, a few days at the most, and some of them did not put in evidence an unquestionable tidal current, but a number of them did. A plotting of these latter showed that the results of the approximate harmonic analyses that were made could not be far from the truth. The velocities found ranged in general from 0.05 to 0.3 knot. It may be of interest to remark that the times and directions of the current were in general agreement with Harris's theory of stationary tidal oscillations. The observations, of course, were made before this theory was formulated, but they were not reduced for tidal purposes till some time after the theory was published, so that they serve as a partial confirmation of it.

If an expedition were sent out to determine tidal currents at sea in somewhat the way here suggested, it would have to occupy one spot for several days, or preferably longer. While the vessel remained on the spot for current observations there would be an excellent opportunity for other kinds of scientific observation, magnetic, geophysical and biological. The intensity of gravity at sea is a great desideratum in geophysics and as soon as adequate apparatus is devised for the purpose observations of gravity should certainly be made in connection with observations of the currents.

EARTH TIDES AND THE VARIATION OF LATITUDE

Just as we may make a harmonic analysis of the readings of a horizontal pendulum or a Michelson tube in order to evaluate the earth tides, so for the same purpose we may make a harmonic analysis of latitude observations. In all three cases we are observing the direction of the vertical or plumb line. In the first two cases the vertical is referred to some mean position determined on the instrument itself and connected with the ground immediately around it, and thus shifting its position as the ground tilts under the influence of the tide-producing forces in the earth and under the load of the oceanic tides. In observations of the latitude the direction of the vertical is referred not to the ground round about the instrument, but to the direction of the earth's axis. The tilting of the ground is allowed for when the level readings are taken and the proper corrections for them applied. This absence of the tilting enables us to get a hold on the problem of the earth tides somewhat different from that afforded by observation with the horizontal pendulum or with the tube and interferometer.

[1] Appendices to Reports of the U. S. Coast and Geodetic Survey for 1885, 1886, 1887, 1889 and 1890. More especially that for 1890, which contains an account of the apparatus used.

[2] For the tidal data deduced see Harris's Manual of Tides, Part V (U. S. Coast and Geodetic Survey, Report for 1907, Appendix 6), 409–13.

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The latitude observations most obviously appropriate for such a harmonic analysis are those of the international latitude service and I believe that they should be systematically discussed in this manner. Some preliminary work of this sort has been done by Shida and Matsuyama,[1] and Shida has proposed to the International Geodetic Association that it undertake the work. Further work on the subject has been done by Przbyllok, whose work has perhaps already been published, though without coming generally to the attention of scientists on this side of the water[2] on account of still unsettled international conditions. I believe the International Geodetic and Geophysical Union should plan to continue the work.

SUMMARY

The observation and reduction of the long-period oceanic tides should not be neglected. The equilibrium theory has not been as fully developed as is desirable and an attempt should be made to allow both for the self-attraction of the water and for the presence of the continents. When this has been done and observation compared with theory, it seems probable that a good value for the long-period earth tides will result. To get good results for the short-period earth tides the oceanic tides of like period must be known and their effects allowed for. One promising means of getting this knowledge seems to be a study of the oceanic tidal currents, which appears to be more feasible than the direct observations of the tides themselves. While the currents were being observed other scientific observations could be made. The earth tides affect the plumb line and their effects must therefore be present in the observations of the International Latitude Service. It is desirable to continue the discussion of these observations in order to throw light on the earth tides.

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[1] "Memoirs of the College of Science and Engineering," Kyoto Imperial University, IV, no. 1, 1912, 277.

[2] "M. le. Prof. Przybyllok a tâché de déterminer plus exactement les constantes de quelques termes périodiques dont les observations du service international des latitudes avaient fait connaitre l'existence; il s'est surtout occupé à déduire des observations astronomiques les constantes de la marée M_2 dans le mouvement de la verticale de la terre considerée comme corps élastique. Les resultats seront publiés sous peu dans les Astron. Nachrichten."—From Rapport sur les Travaux du Bureau Central de l'Association Géodésique Internationale en 1920, p. 3 (dated Jan., 1921).

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SOLAR RADIATION AND TERRESTRIAL PHENOMENA

By C. G. Abbot

SOLAR RADIATION

Its Variability and Its Relations to the Atmosphere

For more than fifteen years the Astrophysical Observatory of the Smithsonian Institution has been engaged in making measurements of the radiation of the sun. These measurements have indicated that the sun's emission is variable. The Institution now maintains two stations—one in Arizona and the other in Chile—for observing the solar variability. Telegraphic reports of the results obtained in Chile have been forwarded to Buenos Aires and Rio de Janeiro for the use of the meteorological services of Argentina and Brazil.

The variation of the solar emission is of two kinds—one, of long period, associated with variations in the visible solar phenomena like sunspots, faculæ, prominences, and the like; the other, of short irregular period, apparently depending upon inequalities of radiation in different directions, which, rotating with the sun, produce at the earth the variation just mentioned. This hypothesis is confirmed by the photo-electric cell observations of Guthnick, who found variations of Saturn occurring earlier or later than corresponding ones in solar radiation observed in Chile, depending on the heliocentric longitudes of the earth and Saturn. Higher values of the solar emission occur when the sunspots are most numerous, which gives rise to a paradox, because the temperature of most meteorological stations is lower at sunspot maximum. This negative correlation between solar emission and terrestrial temperature may be due, however, to a variation in terrestrial cloudiness or to other variations in the composition of the terrestrial atmosphere. It has long been known that a close correlation exists between the sunspot numbers and the variations of terrestrial magnetism. The intermediary mechanism producing this relation is not known. However, it has long been suspected to be due to the bombardment of the earth by ions shot out from the sun. If this is the case, these ions may assist in the production of cloudiness and have also influence in the production of ozone in the higher atmosphere, and thus in one or both of these ways operate on terrestrial temperatures.

Observed variations of the sun have hitherto lain within the maximum range of about 12 percent. It is rare that fluctuations exceeding 3 percent occur within a single week or fortnight. Such studies as have been made, notably those of Mr. Clayton of Buenos Aires, indicate that corresponding to these small fluctuations of the sun there may be variations of several degrees in the mean temperature of meteorological stations. Accordingly it is highly desirable to be able to detect with certainty fluctuations of the solar emission of the order of 1 percent. This is a hard requirement, and it is only within the last year that the establishment of the Arizona

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and Chile stations has warranted the hope that it can be met. Prior to that time, errors of 2 or more percent were probably not infrequent in solar radiation determinations at Mt. Wilson, which until 1918 was the only station in the world where the solar constant observations were being made. Hence we must be required to wait for another decade of years before having a thoroughly satisfactory series of solar radiation measurements to compare with meteorological observations. It would be a very great advantage if two additional solar stations could be equipped in Northern and Southern Africa in the most cloudless and favorable conditions, so that there would be four stations operating under a homogeneous scheme for determining the variability of the sun.

The question arises whether observations of the visible phenomena upon the sun's surface, such as sunspots, faculæ, prominences, or the like, or the observation of terrestrial magnetism, which, as has been said, is closely related to solar phenomena, may furnish some index to solar conditions as valuable as the difficultly obtained determinations of solar radiation. Many statistical comparisons have been published on relations of sunspots and terrestrial phenomena, and to a less degree the other solar appearances have also been correlated thereto. It must be confessed, however, that the result of this enormous amount of work has not been as favorable as would have been hoped. In almost all instances, relations which appeared to hold for a few months or years are reversed in other months or years. Except for the well-known correlation of terrestrial magnetism with the sunspot numbers, there is hardly any other pair of phenomena which would be universally accepted as related. Whether a similar disappointment will attend the proposed studies of solar radiation can not yet be foretold.

Of variable terrestrial influences, the most profoundly active on the solar radiation are the water vapor of the earth's atmosphere and the clouds and haze which are formed from it. Water vapor itself produces powerful absorption bands in the red and infra-red spectrum. Associated with dust, water vapor produces haze which is effective throughout the visible spectrum, and more effective the shorter the wave-length. A great mass of observations of these things has been made by the Smithsonian Institution in connection with its studies of the solar constant of radiation. My colleague, Mr. Fowle, has published a number of papers covering the results of these studies of the subject.

Water vapor itself removes from the direct solar beam which encircles the earth somewhere from 10 to 20 percent of its intensity, depending upon the humidity of the air and other circumstances. The haze may readily produce far greater reduction to the intensity of the solar beam. In addition, we have the clouds. My colleague, Mr. Aldrich, took advantage of the presence of the balloon school near Mt. Wilson to observe from a balloon the reflecting power of the upper surface of the vast oceans of fog which come in from the Pacific and cover the San Gabriel Valley. He found that a continuous sheet of level cloud would reflect away ap-

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proximately 77 percent of the solar rays. As the earth is on the average about 50 percent cloudy, the great effect of these factors on terrestrial temperatures is obvious.

Cloud measurements are among the most unsatisfactory which are recorded by meteorologists. They depend largely on the personal equation and indeed no really adequate statistical study of them has hitherto been available. The preparation of proper automatic observing apparatus and the study of observations of clouds are highly desirable.

TERRESTRIAL RADIATION

Its Relations to the Atmosphere

When we take up the question of the terrestrial radiation, we deal with another region of wave-lengths from that which is covered by the principal incoming solar rays. The direct rays of the sun and the skylight are almost altogether confined to the region of wave-lengths extending from 0.3 micron to 3 microns. The region of the terrestrial radiation extends from 5 microns to 50 microns. Spectrum measurements have been made through a part of this region by my colleague, Mr. Fowle, who used an artificial source of light and a very long column of air of known humidity and carbon dioxide content. In this way he determined the influence of terrestrial humidity upon the rays as far as 17 microns. Beyond that, from 17 to 50 microns, no adequate studies have been made, and indeed the difficulty of making them is immense. Apparently the water vapor existing in a column of air a quarter of a mile long cuts off all terrestrial rays except in the region from 8 microns to 13 microns. In this region, water vapor is almost perfectly transmissible and in this region occurs, therefore, almost all of the terrestrial radiation which, rising from the earth's surface, escapes to space and tends to cool the earth. No constituents of the air at the earth's surface seem to affect the transmissibility of rays between 9 and 12 microns in wave-length, but the matter is quite different in the upper atmosphere. Mr. Fowle found that a strong band of absorption occurs in the direct solar beam squarely in the middle of this very transmissible region. It appears from some measurements of K. Ångstrom that the cause of this band is ozone. Thus, owing to the accidental position of this powerful absorption band in the middle of the only region where the other atmospheric constituents are almost perfectly transmissible, ozone plays an important part in determining terrestrial temperatures.

A research ought to be undertaken to determine the influence of ozone in this region of the terrestrial spectrum, the variations of its amount in the atmosphere, and, in short, the dependence of the terrestrial temperatures on ozone. This research will be very difficult, owing to the long wave-lengths of the rays involved and owing to the occurrence of ozone high up in the terrestrial atmosphere. The investigation would involve the determination of the dependence of the ozone content of the atmosphere on solar radiation as well as on influencing terrestrial conditions.

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Hitherto the measurement of the outgoing terrestrial rays—that is, of the so-called nocturnal radiation—has been very unsatisfactory on account of the lack of a surface which radiates these rays perfectly. Blackened flat surfaces have been used in the instruments employed, but the blackening by means of smoke, lampblack paint, or platinum black are all unsatisfactory because these substances are not full radiators and absorbers for the very long wave-lengths involved. Smoke, for instance, is strongly transmissible beyond 10 microns, and lampblack paint falls off in its absorption very rapidly beyond 15 microns. It is necessary, in order to obtain exact knowledge, to employ some radiating and absorbing instruments which are perfectly radiating and absorbing by reason of their shape; that is to say, which approximate to the so-called absolutely black body.

Hitherto, only one such instrument has been developed, an instrument of which there is yet no published description, namely, the honeycomb pyranometer, or Melikeron, recently invented by Abbot and Aldrich. This instrument consists of 200 deep cells made by fluting a ribbon of thin manganin, the whole presenting a surface comparable to a honeycomb, in which the rays penetrate deeply and are absorbed by repeated reflections. The heat produced by the rays of the sky or outgoing to the sky can be compensated by the introduction of the energy of the electric current. This instrument is but just past its experimental stage, and only a few as yet unpublished measurements have been made with it.

Spectrum observations ought also to be undertaken in the region of wave-lengths from 15 to 50 microns. Rock salt is no longer available in this region, so that some special optical instrument, either a special grating or a special prism to be made of potassium iodide, must be employed.

NEEDED INVESTIGATIONS

It will be seen from these remarks that the most outstanding needs in the investigation of radiation for meteorological purposes are:

First, the continuance of accurate observations of the variation of the sun. These measurements are now going on under the auspices of the Smithsonian Institution in Arizona and Chile, but should preferably be supplemented by the provision of two additional stations, perhaps in North and South Africa, so that variations of the sun could be adequately studied every day in the year. Twenty-seven thousand dollars a year would provide the two stations within two years and maintain them thereafter perpetually.

Second, the painstaking studies of terrestrial cloudiness, its causes and its effect on the incoming of solar radiation.

Third, the study of the quantity and variability of ozone in the upper atmosphere, its dependence on solar and terrestrial conditions, and its influence on terrestrial temperatures.

Fourth, extensive studies with the "black-body" nocturnal radiation

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instrument, and if possible the development of new instruments of that class.

Fifth, an investigation of the effects of terrestrial atmospheric constituents on rays between the wave-lengths of 15 and 50 microns should be undertaken. This involves the development of special optical means to take the place of rock-salt prism as a dispersing medium, since rock salt is non-transmissible to the rays in question.

RELATIONS BETWEEN SOLAR ACTIVITY AND ITS VARIOUS ASPECTS AND THE PHENOMENA OF TERRESTRIAL WEATHER

By C. F. Marvin

My contribution to this discussion is an appeal for a more careful and consistent recognition of the effects and operations of chance in the study of data which may be employed in investigations of solar and terrestrial relations, periodicities, etc. Weather conditions, atmospheric transmission of radiation, magnetic phenomena, sunspots, observed intensities of radiation, and values of like phenomena are subject to large and irregular accidental variations, due account of which must be taken in reaching conclusions.

SOLAR RADIATION

My point of view is illustrated in an admirable manner by figure 1, which serves to show how weak the observational basis still is to justify the claim that there are important irregular changes from day to day in the intensity of solar radiation.

Discussion of diagram.—The vertical lines of the diagram represent throughout each group 25 observations, counted from the beginning of the group. The points on the zigzag lines are simply consecutive observations without reference to the interval of time between observations.

The chronological sequence of the groups of data is represented by the numbers 1, 2, 3, etc. Only a few observations were made between 1902 and 1907 at Washington at wide intervals. From 1905 to 1918 (groups 2 to 7, inclusive) the observations were made at Mount Wilson, Calif. In all these cases the interval between observations is as nearly as possible one day, although periods of bad weather frequently caused two or three, or more days sometimes, to intervene. As a rule, observations were made only from June to November.

Extreme variability is shown in the observations in group 1. Groups 2, 3, 4, 5, and the first portion of 6, show distinctly a lower order of variability, although occasional extremely high and low values occur infrequently.

Beginning at K, group 6 for 1912, great variability again appears in the consecutive values extending into, although diminishing during, 1913. The high value at K, group 6, marks the arrival at Mount Wilson, Calif., of the dust from the Katmai volcanic eruption.

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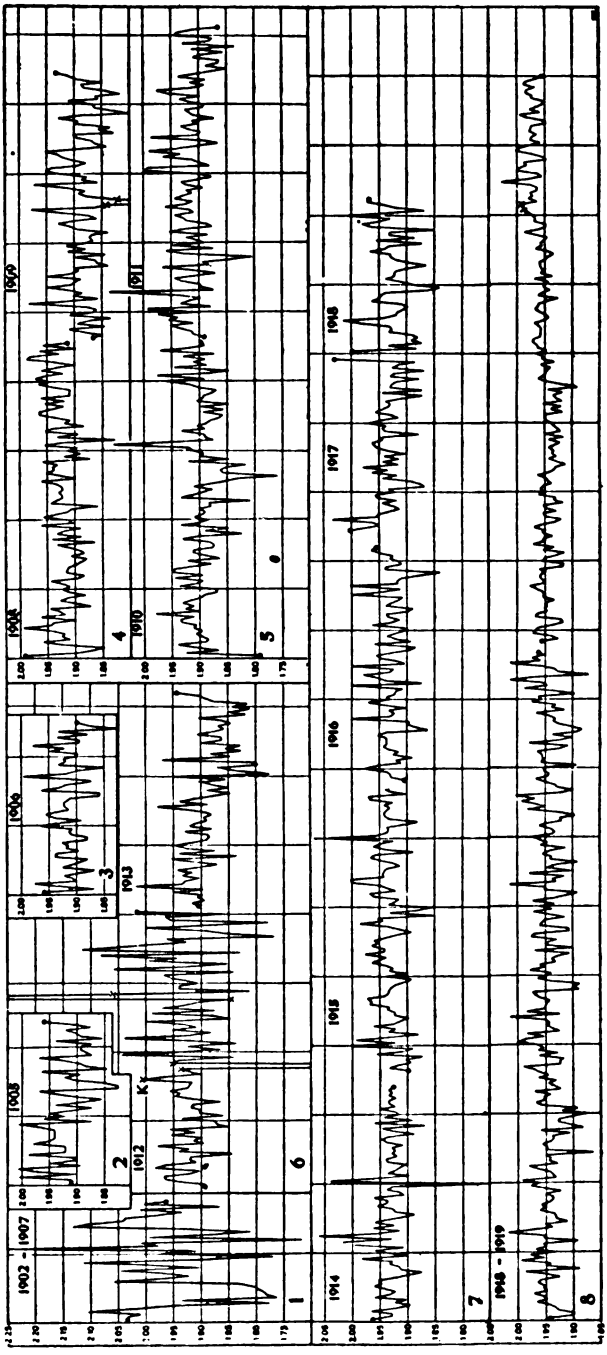

FIG. 1. Diagram of nearly 2000 consecutive observed values of extra-atmospheric intensity of solar radiation, as determined by the Smithsonian Institution from the beginning of observations 1902 to the end of 1919, at stations, Washington, D. C., Mount Wilson, Calif., and Calama, Chile.

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From 1914 to 1918, well after the atmosphere had cleared itself of the Katmai dust, the variability became quite similar to observational results at Mount Wilson prior to the Katmai year, 1912.

Group 8 represents the observations at the station at Calama, Chile.

All observations, including the first portion of group 8, were made by the bolographic method.

Finally, the last group of observations, ending December 31, 1919, were made by a new empirical method based on the bolographic method but permitting two or three observations to be made the same day, thus giving a mean average value for a day of higher accuracy.

This diagram tells a very important story with great force and plainness. Great variations in consecutive values of intensity mark the early observations in Washington with imperfect equipment and poor atmospheric conditions.

Observations at Mount Wilson from 1905 to 1912 show far more nearly constant values of radiation until the arrival of the atmospheric dust from the Katmai volcanic eruption, after which day-to-day or consecutive values showed great variations. Everyone probably ascribes these increased variations, not to increased solar activity, but to inaccuracies of measurement due to atmospheric dust. The large variations disappeared with the dust. Furthermore, some increased accuracy (smaller variations) characterized the observations at the station at Calama, Chile, either because of the better instrumentation, greater observational experience, or better observing conditions, or all of these in combination.

Finally, it is most striking that a further marked reduction in day-to-day variability immediately resulted from the introduction in 1919 of the pyranometer method of observation.

The percentage *probable error of a single value* has been carefully computed for each group of observations and the results are shown graphically in figure 2.

Entirely terrestrial causes easily explain the great changes and gradual diminution in variability shown by the observations, the accuracy of which has been wonderfully increased by improvements in instruments, methods, and location of stations. What are now regarded as good observations *for a single day's work* show a probable error as low as 5 or 6 tenths of one percent. This is remarkable precision. This analysis of the whole body of radiation data brings one face to face with the important question:

Is all of this 5 to 6 tenths of one percent of day-to-day variation in solar radiation intensities real error of measurement only? Or is part of it error of measurement and part real solar change? If the latter, what are the respective amounts of each variation?

Some conclusive answer to this question is necessary before inferences and claims of solar and terrestrial correlations can be set up and justified.

It can never be claimed, of course, that single daily values, however carefully made, are perfectly accurate. Probably simultaneous observa-

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tions at *several* stations is the only answer to this question. Caution is necessary even here, because mere coincidence of variations due absolutely to errors only will come in to affect comparisons at two stations. If, for example, e is the probable variation of, say, a season's work at two per-

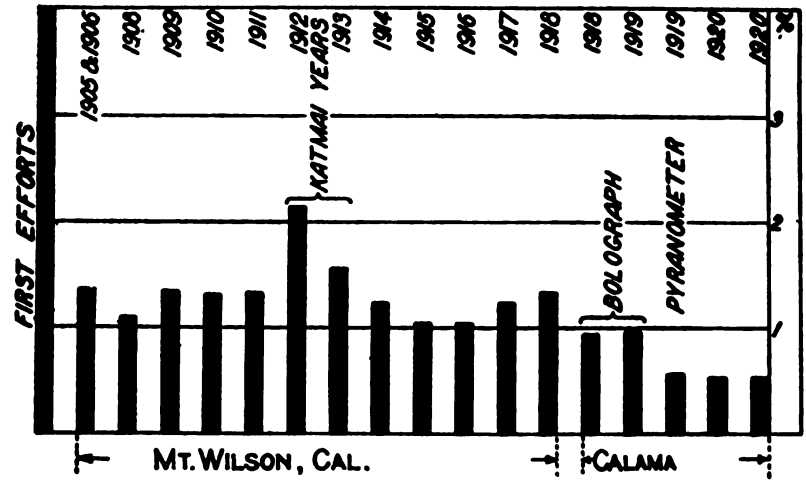

FIG. 2. Height of bars shows probable error of an observation for a single day of the intensity of solar radiation as measured by the Astrophysical Observatory of the Smithsonian Institution at Washington, Mount Wilson, Calif., and Calama, Chile.

fectly equal stations, then for pure chance relations between values the variation ϵ_m of the mean of the two must be

$$\epsilon_m = \frac{\epsilon}{\sqrt{2}}$$

This furnishes an interesting test to apply to the simultaneous observations at Arizona and Chile when these are released by the Smithsonian Institution.

TERRESTRIAL DATA

No serious study of any kind dealing with hidden or obscure relations between data subject to large irregular variations should ever be undertaken without a careful application of the principles of probabilities and a consideration of the operation of the elements of chance upon the phenomena under study.

In the discussion of this portion of the subject the author gave the first

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public account of the mathematical and graphic device which has been designated *The Periodocrite.*

Periodocrite[1] is a word coined from Greek roots signifying a critic, a judge, a decider of periodicities, and is a name applied to a mathematical and graphic method or device which has been developed to aid in the conclusive separation of obscure and hidden cycles and periodicities possessing a real existence from those whose essential features are only such

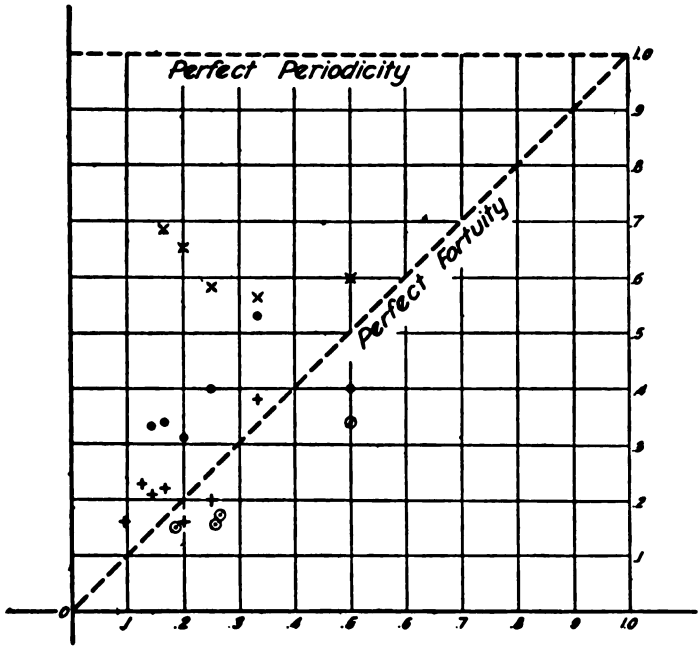

FIG. 3. Rainfall periodocrite: ×, Annual cycle five stations in Iowa, 36-year record; ●, Annual cycle Washington rainfall, 50-year record; +, Annual cycle Boston, Mass., 103-year record, very feebly defined; ⊙, A 15-month sequence Iowa rainfall; other sequences, 15 months, 16 months, one-ninth the variable sunspot period, like the circles, all fall in the class of perfect fortuity.

as would result from, and can be explained by, entirely chance combinations of the data employed.

The periodocrite does not disclose or discover the *length* of suspected periods or cycles. Other methods, such as the harmonic analysis, Schuster's periodogram, or any of the many methods which have been offered for this purpose must first be employed to ascertain the proper length of any suspected cycle.

[1] Prof. C. F. Talman supplied this name from Κεριοδος, a period + Κριτης, a judge, decider, umpire, from Κρινα, to separate, investigate, judge.

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The theory of the periodocrite depends upon the principle that in an entirely fortuitous combination of data the standard deviation, σ_n of a result made up of n individual observations in combination is given by the equation $\sigma_n = \frac{\sigma_o}{\sqrt{n}}$ in which σ_o is the standard deviation of the original data not in combinations.

Writing $y = \frac{\sigma_n}{\sigma_o}$ and $x = \frac{1}{\sqrt{n}}$ we get

$$y = x$$

which is the equation of a line of perfect fortuity passing through the origin of coordinates (see figure 3). It can also be shown that for perfect periodicity $y = \text{constant} = 1$.

The full account of this aid to scientific investigation of periodicities has been published in the *Monthly Weather Review* for March, 1921, to which the reader is referred for the development of this idea and certain related matters dealing with the discussion of meteorological data briefly outlined in the address.

DAILY METEOROLOGICAL CHARTS OF THE WORLD

By Edward H. Bowie

INTRODUCTION

Investigations in the field of general meteorology have been and continue to be restricted and handicapped by the fact that there are not available to investigators daily charts of the world's weather. It is necessary in investigations in meteorology and particularly in weather forecasting that problems now but imperfectly understood be considered from a world-wide viewpoint, for there can be no doubt that much that we call "weather" is not of local origin, but has its inception in the general actions and reactions that involve at times the atmosphere over an entire hemisphere and possibly both hemispheres. Hence, investigation based on a study of daily synoptic charts for a limited area, such as Europe, the United States of North America, or of India, can lead to but an imperfect understanding of the general physical processes that are in operation to produce our day-to-day weather. Moreover, when it is understood how rapid are the changes in speed, direction of movement and magnitude of

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areas of high and low barometric pressure, there arises the natural desire to look into the observable facts over a world-wide area in an attempt to determine the causes of them. Meteorology without a world-wide weather map is laboring under difficulties as great, or greater, without realizing it, than astronomy without its star charts. Hence it is contended that many of the important problems of meteorology will not and cannot be solved until there be available daily synoptic charts of the various meteorological elements of, relatively speaking, the entire world. It would redound to our credit if the American Geophysical Union should become instrumental in bringing this about.

NEED FOR WORLD-WIDE CHARTS

There is reason to believe that meteorology has for its goal the making of accurate forecasts of weather, temperature and wind for long periods in advance. Such an attainment would not only mark a distinct advance in the science of meteorology, but in its practical application would be of great economic importance to the life of the nation.

The problem of making such forecasts has for years received consideration not only from meteorologists of good repute—scientifically speaking—but also from others untrained or at least not having a thorough grasp of the question. Many explanations of the frequently marked deviations from the normal that occur in the meteorological elements at any given place have been given publicity. Much attention has been given to the question of cycles, even more has been given to the question of sunspots, and recently attention has been focused on the so-called variations in the solar constant. But all these efforts fail to offer a method that permits the making of long-range forecasts of a sufficient degree of accuracy to have a practical application of any importance.

One naturally inquires why nothing really definite has been evolved that might be useful in long-range forecasting, and the only possible answer that can be made is that the right combination has not yet been found.

My impression is that the answer will probably be had from a prolonged and careful study of world-wide meteorological conditions, and this study is possible only in the event that daily synoptic charts embracing the major part of the world are available. In my opinion all marked deviations from normal weather and temperature are associated with changes in magnitude and position of the so-called "great centers of action." Any material addition to our knowledge of these must come from the study of world charts, for it is only by such a method that we can hope to gain a more comprehensive knowledge of the general atmospheric circulation and the resulting changes in the centers of action. In Supplement No. 1, *Monthly Weather Review,* 1914 (Bowie and Weightman), it is stated that:

> Conspicuously abnormal pressures in the regions of these so-called "centers of action" are related to marked departures from normal weather and temperature conditions in the United States. Some authorities assume that these abnormal distributions of pressure are due to extra-terrestrial and others assert that they are due to terrestrial causes. If it be true that the solar output is a variable quantity,

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it is possible that the solar variations are associated with marked changes in pressure in the "centers of action," and thus may be found a key for defining for considerable periods in advance the general character of coming weather changes for a given region. If on the other hand abnormal pressure distributions occur with an unvarying solar radiation, the causes thereof must be traced to a terrestrial source. The varying effects of the nearly constant radiation on land and water surfaces and on the air under different conditions of temperature, water vapor content, dust content, etc., are sufficient in the minds of some writers to explain these phenomena, i. e., the changes in the position and magnitude of the "centers of action."

Regardless, however, of the cause of abnormalities in the "centers of action" the importance of their relation to the character and paths of storms in the United States is well recognized and therefore should be carefully considered in day-to-day weather forecasting in the United States. To illustrate: Of the centers of action that affect the weather conditions of the United States east of the Rocky Mountains, the subpermanent high over the middle latitudes of the North Atlantic Ocean is perhaps the most influential. When this is well developed and stable, temperatures above the seasonal average are to be expected over the great central valleys and the eastern and southern states, and the areas of high and low barometer crossing the United States will move in high latitudes and pass on to the ocean by way of the St. Lawrence valley. In fact, all prolonged periods of heat in the regions east of the Rocky Mountains occur simultaneously with the abnormal development of this subpermanent high. When, however, it is weak and ill-defined, cool weather prevails over the eastern half of the country.

Again, the variations in the position and magnitude of the elongated subpermanent area of low pressure that normally extends from southeastern Alaska westward to Kamchatka, have a decided influence on the characters of, and courses followed by, storms that cross the United States. If this Aleutian low is north of its normal position, lows will move along our northern border; whereas, if it is south of its normal position, lows will move far south of their normal tracks and stormy weather with great alternations in temperature will occur over the United States.

Perhaps the best examples of unusual winters in the United States are those of 1917-1918 and 1920-1921. In the former, which was one of great severity, the pressure was abnormally high over Alaska and the Aleutian Islands; while in the latter, which will go down in meteorological history as one of the mildest known, the pressure was much below the normal over those regions.

To be able to formulate correct forecasts, a knowledge of the general circulation is fundamental. It is questionable whether a proper understanding of the general circulation can be gained from monthly averages. It certainly is not as stable as the text books would lead us to believe, for there are frequently marked changes in both the surface and upper air flow. It has been customary to think of the general or primary wind circulations of the two hemispheres as separate and distinct, but this view is not tenable. A cursory examination of plate 14, "Bartholomew's Physical Atlas," Meteorology, volume III, shows a tremendous seasonal interflow between the northern and southern hemispheres, indicating that the two systems of general circulation are in a way interlocked. In the winter of the northern hemisphere the air flows normally from the interior of Asia southward over the Indian Ocean, eastern Africa and the East Indian Archipelago on beyond the equator as far south as northern Australia; in the summer of the northern hemisphere a return flow takes place over essentially the same geographical area. No one can say, for the lack of the necessary data, whether these currents do not bring about

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profound changes from normal weather and temperature conditions over large areas outside the regions where these flows and counterflows are in operation, but it seems logical to suppose that such is the case. Further, the trades and antitrades are probably not fully understood. Certainly these wind systems undergo pronounced changes that are independent of the seasonal changes. In connection with the antitrades, Sir Napier Shaw in a recent number of *Nature* remarks:

> At the same time I may remark that I find it very difficult to grasp the meaning that is intended by "anti-trades." The original convection theory suggested that the anti-trade was the trade returning up aloft above its old path, but, so far as I can understand the situation, the track of the wind from the equator must begin from the east and become southwest by what I will describe as the hurricane track. On the other hand, a southwest wind may be a part of the westerly circulation diverted; the difference of origin of the observed southwesterly wind is of some dynamical importance.

It seems possible that the antitrade may be a northward extension of the southeast trade of the southern hemisphere, which on crossing the equator is turned to the right by the deflective force of the earth's rotation, and being warmer and of less density, overruns the low-lying northeast trade. But this is not definitely known and sufficient data are not at hand to prove or disprove the assertion.

Bjerknes has recently given meteorology the term "polar front," a line of discontinuity separating the polarward from the equatorward flowing winds, and he has urged the collection of daily meteorological observations from larger geographical areas that this "polar front" may be delineated on the weather charts for the aid of the forecaster. He believes this essential to forecasting, for the theory he advances places the origin of cyclones and consequently all marked variations in weather, temperature and wind changes along this line of discontinuity. His presentation of the idea of the "polar front" and its attendant phenomena is worthy of him, and augments the necessity of observations over large geographical areas in weather forecasting.

It will be seen from the foregoing that meteorology must in the near future consider the question of securing observations from every accessible place and assembling them for the construction of daily world-wide weather charts at one or more great world centers for intensive study. First, there must be a skeletonized chart based on observations collected by cable, radio and land lines, and, second, a more nearly perfect and complete chart based on the same observations supplemented by those collected from remote land areas in which cable or radio is not available and from ships at sea. The former chart would serve for day-to-day forecasting; the latter, for study purposes and eventually for long-range or seasonal forecasting.

HISTORY OF THE MOVEMENT FOR WORLD-WIDE CHARTS

The need of a daily synoptic survey of the earth's atmosphere was coincident no doubt with the beginning of synoptic weather charts, which was at approximately the middle of the nineteenth century. We learn

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that at the first meeting of the International Meteorological Congress, assembled at Vienna in 1873, a proposition was adopted to the effect:

> That it is desirable, with a view to their exchange, that at least one uniform observation, of such a character as to be suitable for the preparation of synoptic charts, be taken and recorded daily and simultaneously throughout the world.

Later, on December 9, 1876, it was announced that the United States, through the Chief Signal Officer, U. S. A., no doubt inspired by the late Prof. Cleveland Abbe, then assistant to the Chief Signal Officer, was undertaking the task of establishing cooperation for the recording and exchange of simultaneous meteorological observations between the United States and the following named countries: Algeria, Austria, Belgium, Great Britain, Denmark, France, Germany, Italy, The Netherlands, Norway, Sweden, Switzerland, Turkey, Greece, Canada, the Hawaiian Islands, Dutch Guiana and Japan. This cooperation extended to naval and merchant vessels of these nations, and thus were secured the simultaneous observations of atmospheric changes over much of the northern hemisphere. Thus came about the "Bulletin of the International Meteorological Observations," published by the Signal Service, U. S. A., for the years 1877–1887—incomplete, it is true, as to world-wide weather maps, but a remarkable contribution which has left its impress on meteorology even until today.

An effort to accomplish the preparation of northern hemisphere weather maps by means of daily telegraphic reports for the purpose of extending the forecast period to cover the general weather of the United States was undertaken by the U. S. Weather Bureau in 1907, and the area covered by such reports grew until the outbreak of the Great War in 1914, when the scheme was unavoidedly interrupted. No other really effective efforts looking to the preparation and publication of even partial world-wide daily synoptic charts are known to me.

PRESENT STATUS OF DAILY SYNOPTIC METEOROLOGICAL CHARTS

Nothing approaching a world-wide daily synoptic chart is prepared and published by the meteorological service of any nation. Instead, every, or nearly every, national meteorological service decides for itself: (a) the scale of the map, (b) the units of measurement, and (c) to a greater or less extent the hours of observation. In addition to the various charts of land observations, charts are also made of the meteorological conditions over one or more of the oceans. Daily weather maps for their respective geographic areas are now prepared and published by the United States, Canada, Mexico, Argentina, Chile, Brazil, Japan, China (Zi-ka-wei Observatory), Australia, India, South Africa, Great Britain, France, Portugal, Belgium, The Netherlands, Norway, Sweden, Denmark, Germany, Austria (?), Russia (?) and others. There is thus available a tremendous mass of valuable data awaiting action that will assemble them into one standard, world-wide weather map which will permit investigations in meteorology to be carried beyond any point now possible.

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RECOMMENDATIONS

This matter is believed to be of such importance at the present time that it is contemplated recommending in appropriate form that some action be taken by the Geophysical Union for the accomplishment of the desired objects through international cooperation.

There is no doubt in the minds of those familiar with the present status of meteorology that the carrying out of this proposal will be well worth while, not only from a scientific standpoint but also from the standpoint of service to the general public.

The preparation of the data for charting and the printing or lithographing of the charts for American use could best be done by the U. S. Weather Bureau, but to do this, additional funds must be provided through congressional appropriation.

WORLD AEROLOGY

By Willis Ray Gregg

Aerology may be very simply defined as "the study of the free air";[1] world aerology, as an extension of that study to all parts of the world. By this we mean not only the continental areas, but the seas as well; and not merely sections of a hemisphere, but from pole to pole. It is our purpose to review very briefly (1) what has been and what is being done toward this end; (2) more particularly, to outline what *can at once* and also what *should* later from time to time be undertaken.

PAST AND PRESENT

Methods.—As early as the middle of the 18th century kites were used, by William Wilson at Glasgow University and by Benjamin Franklin at Philadelphia, in making free-air observations. Others followed their example, with more or less success, but it was not until about 1890 that the kite came into general use for this purpose.

So far as known, the first manned balloon ascent in the interests of science was made by Robertson and Lhöest in 1803. During the next 75 years much interesting information as to free-air conditions was obtained by means of numerous similar ascents, among the most notable of which were the classic voyages of Glaisher, Flammarion, de Fonvielle and Tissandier.[2] Unlike the kite, however, the manned balloon has in recent years suffered a decline as a means of aerological exploration, because of the large expense involved and the impossibility of providing satisfactory exposure of the instruments. Although the observations made by these two methods were extremely interesting, yet prior to 1890 they yielded comparatively little of value, owing to their fragmentary character and none too great accuracy.

[1] See "Meteorological Glossary," British Meteorological Office, M. O. 225 ii, 1918, p. 16. London.

[2] "Travels in the Air," edited by James Glaisher, F. R. S., Philadelphia, 1871.

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Since 1890 rapid strides have been made. The kite has been developed from a mere toy into a very efficient means of exploration. With it heights slightly exceeding 7 kilometers have been reached, although the average daily height is a little under 3 kilometers. Recording instruments carried by these kites furnish information as to pressure, temperature, humidity and wind at various heights and their changes from day to day, season to season, and under various types of weather at the earth's surface. Since the kite can be flown only when there is appreciable air movement, its use has in some instances been supplemented by that of a small captive balloon, and thus we have some records in calm weather. Generally speaking, however, the captive balloon has proved to be rather unsatisfactory and its use has been largely discontinued.

For exploring the air to greater heights than can be reached with kites, so-called "sounding" balloons are used. Made of pure rubber, filled with hydrogen and carrying self-recording instruments, these balloons have given us information of great interest and value to heights of 30 kilometers or more. Smaller, so-called "pilot" balloons, because of their comparative cheapness and convenience in handling, have in recent years come into general use for observing wind direction and speed. On clear days, when the wind is not too strong, these balloons can be followed by means of theodolites to heights well above 10 kilometers.

All of these methods have been rather extensively employed in Europe, particularly in England, France and Germany, and in the central and eastern portions of the United States. Some of them have been used to a limited extent also in Canada, Australia, Java and Argentina, as well as on a few expeditions of short duration to different parts of the Atlantic Ocean. In addition, there should be mentioned the great mass of cloud observations, some of which, particularly those during the International Campaign of 1896–97, were accurately and systematically made by means of nephoscopes and theodolites and furnished information, not only as to the heights and other characteristics of the clouds themselves, but also as to wind conditions at various levels.

Results.—Although a considerable amount of data has been gathered by the methods above outlined, it must be confessed that we know even yet comparatively little with reference to what is going on in the atmosphere above the earth's surface. The general state of our knowledge can be briefly summarized as follows:

(a) For parts of Europe and the United States we have well established average monthly, seasonal and annual values of all the meteorological elements from the surface to about the 5-kilometer level. Pressure of course always diminishes with altitude; temperature and humidity do so on the average, except that in the north-central portions of the United States there is a temperature inversion in the lower levels during the winter months; wind velocity increases, sharply in the lowest half kilometer, more gradually above that height; and wind direction is in the mean very nearly westerly at all levels, except in the southern part of the United States, where, during the summer, it is south to east near the surface.

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(b) Of conditions between 5 and 25 to 30 kilometers we have rather limited information. We know that the temperature continues to diminish at a fairly uniform rate until a height of 8 to 18 kilometers is reached—this height varying with latitude, season, and sea-level pressure; above this limiting height the temperature ceases to diminish and in fact has a tendency to increase to some extent, at any rate during the summer half of the year. The boundary plane between the lower region of temperature decrease, known as the troposphere, and the upper region of little temperature change, known as the stratosphere, is in general well defined. Clouds do not occur in the stratosphere and winds generally have lower speeds here than in the troposphere. There is some evidence that at still greater heights wind direction changes from westerly to easterly, but data on this point are not conclusive. Other characteristics of the stratosphere are the lower temperature and greater height of its base in low than in high latitudes and during falling than during rising air pressure at the earth's surface; also, its greater height in summer than in winter.

(c) Of the relations found to exist between surface weather and free-air conditions, perhaps none is more significant than that between surface temperature distribution and winds in the upper levels. As is well known, the winds at and very near the surface conform quite closely to the surface pressure gradient, but at greater heights they often depart widely from it. If the temperature is fairly uniform over wide areas, the free-air winds are very nearly parallel to the surface isobars, and show that anti-cyclones and cyclones extend as such to great heights. If, on the other hand, the latitudinal temperature gradients are steep at the surface and also, though to a less extent, in the higher levels, then the surface pressure systems lose their identity at a very low altitude, the isobars opening out on the north side of cyclones and on the south side of anti-cyclones, and the winds veering or backing from those at the surface in conformity with the altered pressure distribution at the higher levels. This relation of free-air winds to surface temperature distribution has not thus far been accorded the attention it deserves. With the development of aviation and the resulting demand for accurate free-air wind forecasts, the significance of this relation must necessarily receive increasing recognition.

The foregoing summary is very sketchy and incomplete, but it will serve as a basis for the consideration of problems which must be attacked in the future, if real progress is to be made.

THE FUTURE

The present age, to a greater extent than any in the past, may be called an "age of projects." More and more mankind is giving heed to Emerson's exhortation, "Hitch your wagon to a star," and perhaps this is an especially appropriate motto for the aerologist to adopt as his own. Of the many ambitious plans that we read and hear about, some undoubtedly will yield negative results only, but it is equally certain that others will contribute very materially to human welfare. And it is better that some

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should fail than that none should be tried. The projects to be presented here are not visionary, but on the other hand very practical ones, and for the most part they are not difficult to carry out. They will be stated in the order in which it is believed they can be put into execution.

1. *Further study of data already accumulated.*—There is much material now available that has not been summarized and studied in detail or properly applied to the problems of aviation and forecasting, and to the solution of perplexing questions relative to the larger features of atmospheric circulation. One of the first things to be undertaken is the preparation of such a summary. Very few men, outside of the government services, are giving the subject any thought. Those *in* the government services can devote comparatively little time to it, because of other more pressing duties. There are needed at once for this purpose half a dozen well-trained men (well trained both in theory and in field experience) who can give all of their time to this subject for a period of 3 or 4 years. This, then, is a comparatively simple project—one requiring only a small outlay of funds, but giving results of immense value.

2. *Development of new methods of observation.*—As already stated, nearly all observing at the present time is done with nephoscopes, kites, pilot and sounding balloons. All of these methods have well-known limitations, but should be continued. There should be added, if possible, observations with kite balloons and airplanes. Kite balloons, although more expensive than kites and pilot balloons, would furnish data of correspondingly greater value, since they could be used with greater regularity, irrespective of weather conditions. Indeed, their use would be limited only by very high winds, and records could thus be obtained under conditions unfavorable for kites; in other words, by combining the two methods, the atmosphere could be explored up to 3 kilometers practically every day in the year. Like kites, their use would be restricted to regions not frequented by airplanes, because of the danger of fouling with the cable. Their use would be further restricted to places where hydrogen could be obtained. These limitations, however, are no more serious than others under which we now labor and can be overcome at comparatively small expense, when we consider the great value of the results obtained.

Development of suitable apparatus for use in airplanes should be pushed vigorously. As aviation expands, there will necessarily be a large number of places at which regular daily flights will be made at and above the fields for purposes of testing the machines and the training of pilots. Observations during these flights would add little expense and would provide information not otherwise obtainable, such as the thickness of cloud layers, etc. Work along this line has been done in England and France, but thus far to no great extent in this country, because of inadequate appropriations. It will be taken up as soon as funds for the purpose are made available.

3. *Extension of observation stations to all parts of the world.*—This must be done through international cooperation, but the United States can

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make a good start by more completely covering its own territory, including Alaska, the Hawaiian and Philippine Islands, etc. In making such an extension, and a further extension later by all other countries, two separate and distinct purposes are to be served: (a) the furnishing of current information of immediate practical value to aviators; (b) the

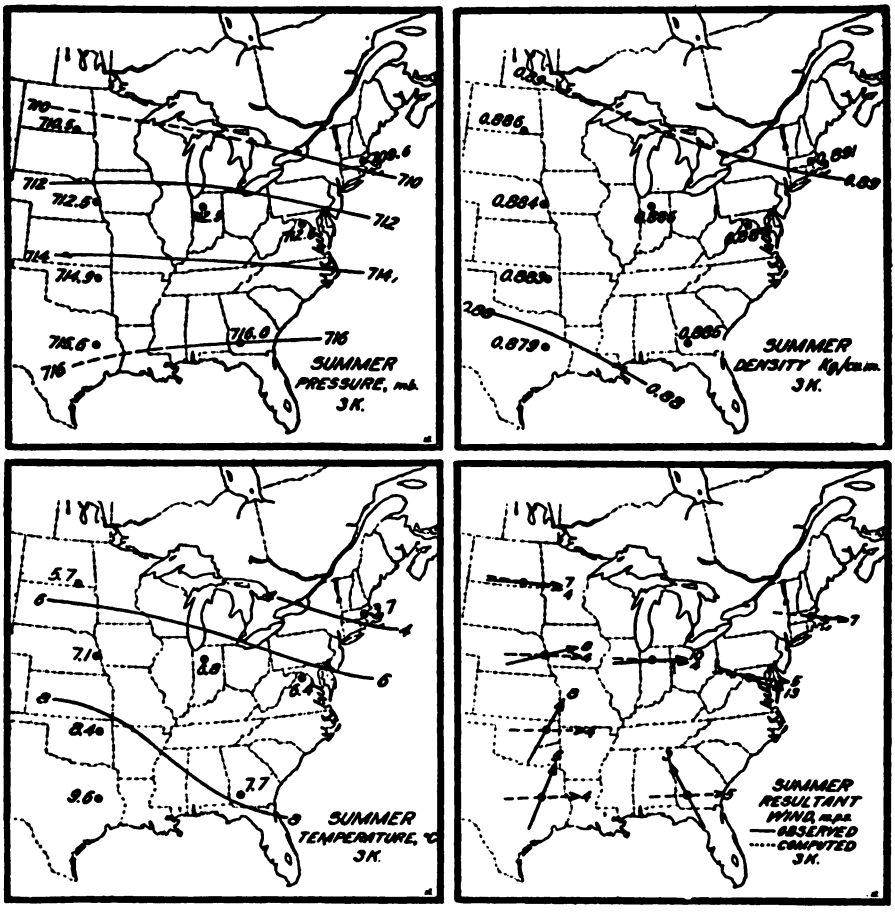

FIG. 4. Average summer values of pressure, temperature, density and resultant wind at the 3-kilometer level.

collection of statistical information required to explain the physical causes of various phenomena and, as a necessary consequence, to increase the accuracy of weather forecasting. For the first purpose it is sufficient to establish observing stations having comparatively simple equipment, by means of which the atmosphere may be explored to moderate heights only. It is not essential that temperature and humidity be observed, but it *is* essential that frequent observations be made of wind, cloudiness and visi-

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bility, these being the factors of vital interest to aviators. For the second purpose a much more comprehensive program is necessary. We should have accurate values of temperature and moisture as well as of wind. Observations should extend to as great heights and be as nearly continuous as possible, in order that we may know the diurnal and annual variations throughout the troposphere and much of the stratosphere; the characteristics of the atmosphere under different types of surface pressure and temperature distribution; and latitudinal and longitudinal variations. It is absolutely necessary that these data be collected and carefully studied. Otherwise we shall continue to be bombarded by theories and, worse still, by sweeping conclusions which can hardly stand the test of further light on the subject, but which (and this is the unfortunate feature), being advanced by men of recognized standing, find their way into textbooks as *facts* and thus start the student upon an entirely wrong track. As in all other matters, so in meteorology it is regrettably true that "a little learning is a dangerous thing." Specific references need not be made, but it may be remarked that in the past year or so there have been some particularly glaring instances of the promulgation of theories, based upon incomplete data, and of the more or less universal acceptance of those theories.

As examples of the kind of information needed, figures 4 and 5 are shown. They are based upon all observations thus far made with kites in this country, and give respectively average summer and winter values of pressure, temperature, density and resultant wind at the 3-kilometer level. These and similar charts for other levels, also charts showing relative humidity and vapor pressure, form part of a summary now in preparation, to be known as "An Aerological Survey of the United States." Some of the more prominent features shown in figures 4 and 5 are: (a) the close relation between the latitudinal pressure and temperature gradients; (b) the small latitudinal density gradient, owing to the counterbalancing effects of pressure and temperature, i. e., density varies directly with pressure, inversely with temperature; (c) the slight southward trend of lines of equal values of these elements from the interior to the eastern portions of the country; (d) the close agreement between computed and observed resultant winds in the winter season. The less satisfactory agreement in summer is due to the greater frequency of days with winds too light for kite flying (another argument for the use of kite balloons and airplanes); and (e) the small latitudinal difference in resultant wind speeds, due to the fact that these vary directly with the pressure gradient, but *inversely* with the sine of the latitude.

It is probably not a coincidence, but rather a matter of considerable significance, that the average movement of cyclones in the United States during the winter, as determined by Bowie and Weightman, is 13.4 m.p.s.[1] —a value in striking agreement with the resultant wind shown in figure 5. The agreement is less close in summer, apparently indicating that cyclones

[1] Types of storms of the United States and their average movements. *Monthly Weather Review*, Supplement no. 1, p. 8.

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extend to a greater height in that season than in winter, and this, as already pointed out, is undoubtedly the case.

These figures, however, are not shown with the view of discussing them as such, but rather with that of indicating how important it is that we obtain similar information for all other parts of the world—the sea as

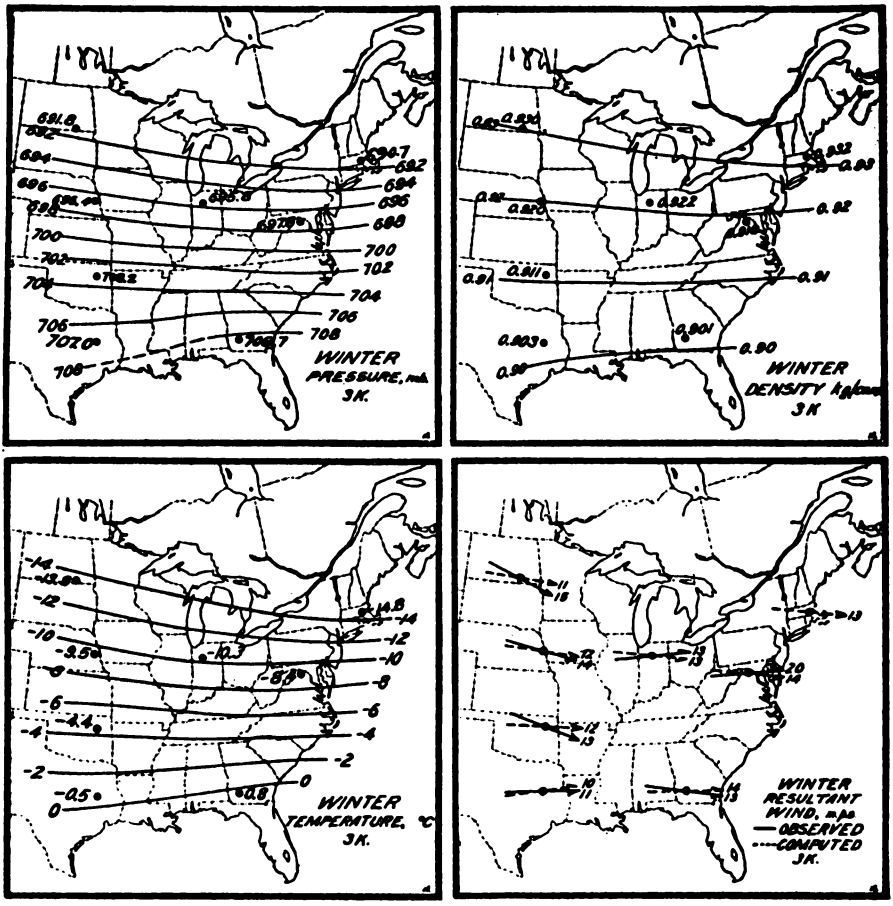

FIG. 5. Average winter values of pressure, temperature, density and resultant wind at the 3-kilometer level.

well as the land. Obviously, it is impossible to carry out this program at once in its entirety. We must therefore start with the most pressing needs, as follows:

It is well known that the type of pressure distribution prevailing in the region of Alaska exercises a dominating influence on the weather of the United States. Similar relations are found in other parts of the northern

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hemisphere and emphasize the importance of having a network of stations, observations from which would make possible the construction of world weather maps—a subject which has already been presented by Major Bowie (see page 36). As indicated by him, such observations would enable the forecaster to follow from day to day the eastward march of the so-called "polar front."[1] There should be a string of stations as far north as possible and, in the southern hemisphere, another as far south as possible. Some of these stations at least should be provided with equipment for free-air exploration, this exploration to include accurate observations of wind and clouds by means of theodolites and nephoscopes. A few should, in addition, be equipped for making measurements of temperature and moisture, as well as wind, to great heights. These few would necessarily have to be not too far removed from sources of supply, but the others, if equipped with radio, could well be located as far north as living conditions would permit.

It has been said that definite meteorological laws will be established only from observations made at sea. These are difficult, perhaps impossible at the present time, to make, but there are numerous small islands where the influences of the land upon the atmosphere are negligible. Data of inestimable value can be obtained by establishing free-air observing stations in Bermuda, the West Indies, the Azores and the islands of the Pacific; also in Central America, where continental effects would be small. We know none too much about the prevailing westerlies, but our knowledge of them is voluminous compared to that of the antitrades. Such a network of stations as I have indicated, especially if operated for a considerable period of time and supplemented by observations from ships at sea, would provide the information now lacking and, in addition, would solve the much discussed and still unsettled questions of the exchange of air between the equator and the poles, the movements of hurricanes, etc.

Aside from the settlement of these theoretical questions, and perhaps more important, is the value of such observations for daily use in forecasting. With the development of radio communication, reports from these stations should be capable of speedy transmission to forecast centers, where they could be charted on upper-air maps, supplementary to the world weather maps, already discussed. Their value to aviators need not be argued. Can anyone doubt their even greater value, with further study, to the forecasting, not only of day-to-day weather, but also of week-to-week, month-to-month and possibly year-to-year changes in weather?

[1] See V. Bjerknes. The meteorology of the temperate zone and the general atmospheric circulation. *Nature*, June 24, 1920, 522–524.

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WORLD DIGEST OF METEOROLOGICAL DATA

By W. J. Humphreys

Meteorological data are gathered for, and serve, many purposes:

They are abundantly used in forecasting the weather of the morrow, but obviously used only once, and hence for this purpose need not be recorded.

They also are collected in the course of special studies, but the completion of each investigation renders useless the preservation of the particular material treated. It is the generalization—the law—that counts, and not the isolated values from which it happened to be deduced.

Finally, they are essential to many studies of interrelations between meteorological elements; to a knowledge of the relation of the weather in one part of the world to that occurring either previously, simultaneously, or subsequently, in others; and to all accurate knowledge of climates and their changes. For each of these purposes it is necessary that meteorological data be indefinitely accumulated, and equally necessary that they be put in manageable form and made widely available.

Now, although fully three-fourths of the surface of the earth is a meteorological blank, the mass of data already accumulated from the remaining one-fourth is so vast and heterogeneous as to be beyond the power of any individual to analyze and study in detail. Furthermore, even approximately complete sets of these data have been assembled in very few places. Hence much of the information contained in this meteorological material certainly is not only unknown, but even beyond the power of individual effort to know.

Therefore it is suggested that a comprehensive digest of all existing meteorological data be made and published. A possible way of accomplishing this great labor is as follows:

1. Let the data to be published (monthly and annual normals and departures therefrom, special phenomena, and what not), the units to be used, the form of publication, and all other details of this kind, be agreed to internationally.
2. Let each country furnish the digest of its own data.
3. Let the digest for each country consist of the individual digests for, and made at, its several meteorological stations.
4. Let some one agency, supplied with adequate funds and personnel, be charged with the duty of assembling sporadic data from countries that have no official meteorological organization; and with the further important duty of editing the entire work.

In this way the proposed vast labor would be divided up between several countries, and further subdivided among many individuals in each country, and the product of the combined effort of the many workers—the digest of all the world's meteorological data—soon made available to every institution that needs it and to every individual who wishes to study it.

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There then could be students of world meteorological data, and would be; now there is none—and can not be.

It will be recognized of course that the plea here is for a greater "Réseau Mondial," one covering a larger number of meteorological elements than does that splendid publication, and also extending back to the beginning of meteorological observations. It would both include and supplement the data contained in the present Réseau Mondial, but would not take the latter's place as a convenient annual summary of the more important elements of the world's weather at selected places.

GENERAL ADOPTION OF THE CENTESIMAL SYSTEM OF ANGULAR MEASUREMENT—WITH APPLICATION TO ANEMOMETERS AND NEPHOSCOPES

By Alexander McAdie

Reviewing an article on "Uniformity in Aerographic Notation," [1] Sir Napier Shaw [2] calls attention to the common usage of the capital letters N.E.S.W. for wind directions, and the established usage in Physics of N for Avogadro's constant, E for Energy, S for Entropy and W for internal work.

The criticism is constructive and suggestive. The question arises: Is it not desirable to follow the lead of navigator and magnetician and use degrees instead of letters to indicate direction of air flow? There are some distinct gains from such a usage for the aerographer or chart maker of the winds. Official weather bureaus record direction on a 45-degree basis; that is, eight directions are given. It has long been felt that such records were not sufficiently detailed. Precision, detail and convenience are gained by the use of the degree.

There is no mechanical difficulty in getting continuous records of wind direction for the entire circle. Many forms of anemoscope give such records. Figure 6 gives such a record sheet based on one used at Blue Hill for 35 years. The eight cardinal directions are noted; but instead of 32 points of the compass, as heretofore, the intervals are at 10 degrees, and thus 36 divisional lines appear instead of the old compass point 11.25. For convenience in computation there is also introduced Greenwich Mean Civil Time, beginning at an hour appropriate for changing records on this coast, noon 75th meridian time being 17 hours Greenwich time. The sheet, however, is adaptable to any station meridian time, by inserting the proper hour in the S.M.T. column. If, however, the centesimal system is to be used, the number of divisional lines is increased to 40, and since there are 400 grads in the circle, each division represents 10 grads or 9 degrees.

[1] H. A., 83–4, pp. 169–180.
[2] *Nature*, Nov. 4, 1919.

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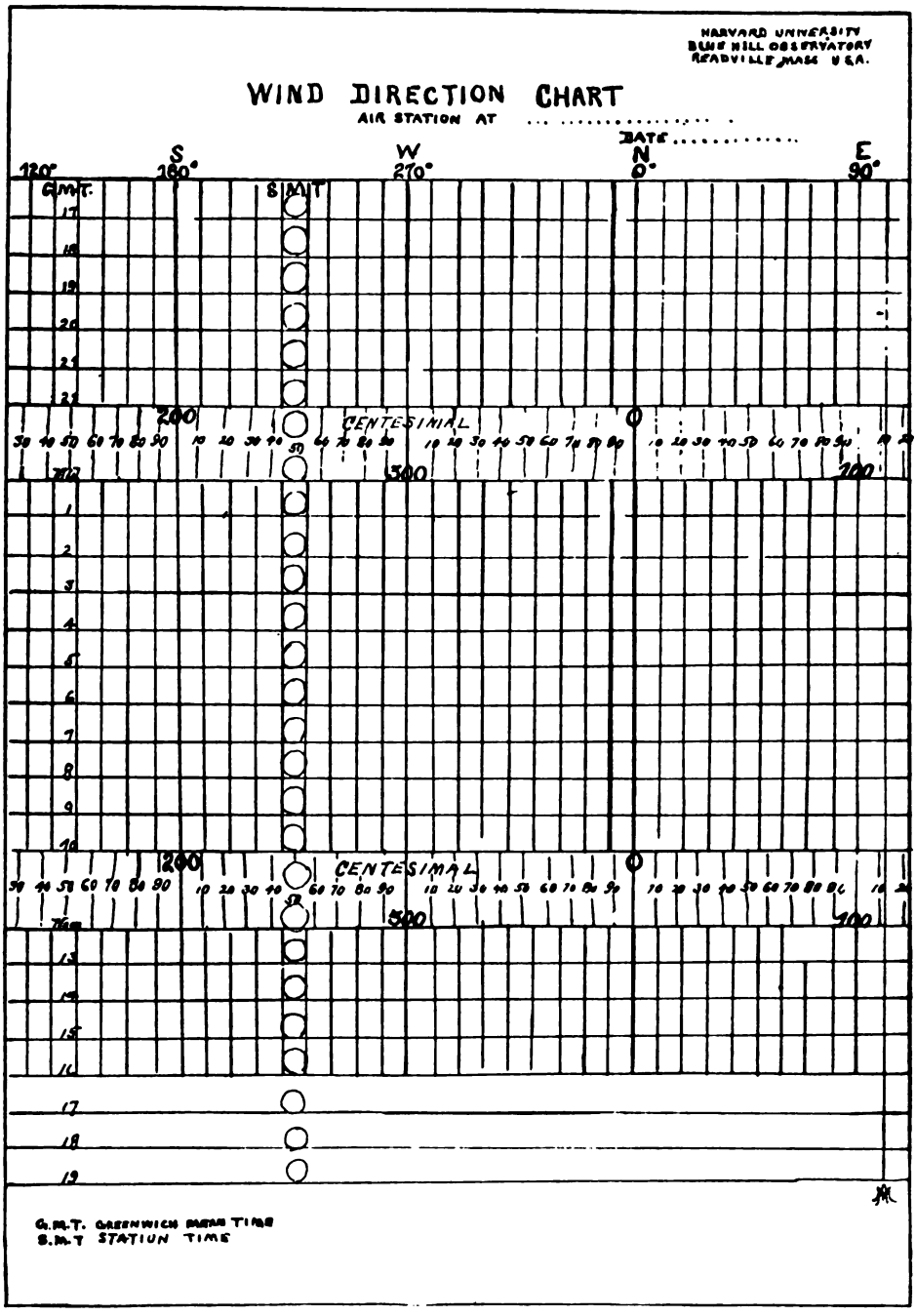

FIG. 6. Wind-direction chart.

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By the use of such charts, the words westerly, easterly, and other like terms disappear and the flow is more definitely described. Wind vanes, unfortunately, do not fly *with* the wind, but against the wind, the arrowhead pointing into the wind. On the other hand, in all charts of air flow, the arrows fly with the stream.

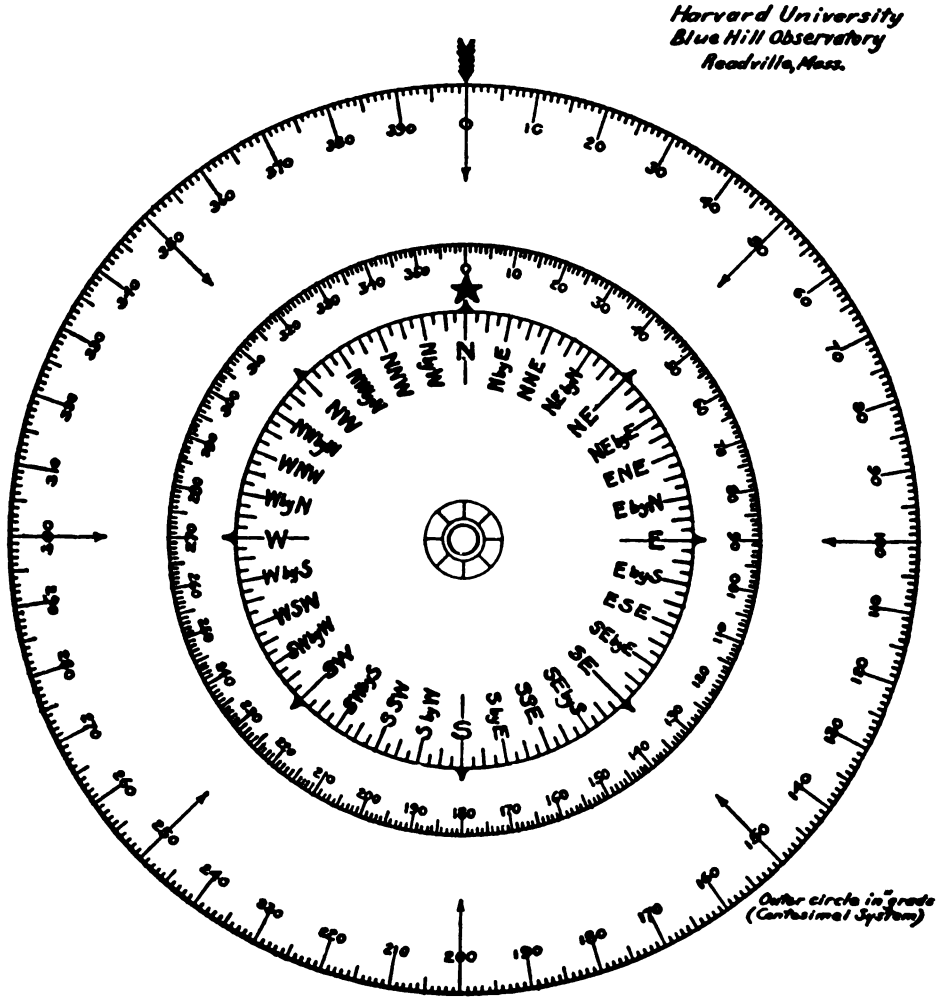

FIG. 7. Wind protractor for use with McAdie nephoscope.

The direction of flow is read to the right, starting from zero, at the north; and thus an east wind is definitely recorded as 100 grads (or 90 degrees), and a south wind as 200 grads (or 180).

The value of the natural sine of 100 grads is 1. The following abridged table gives the sines, cosines, tangents and cotangents of every 10 grads:

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grads	sine	cosine	tangent	cotangent
100	1.00000	0.0000	∞	0.0000
90	.9877	0.1546	6.3138	0.1584
80	.9511	0.3090	3.0777	0.3249
70	.8910	0.4540	1.9626	0.5095
60	.8090	0.5878	1.3764	0.7265
50	.7071	0.7071	1.0000	1.0000
40	.5878	0.8090	0.7265	1.3764
30	.4540	0.8910	0.5095	1.9626
20	.3090	0.9511	0.3249	3.0777
10	.1546	0.9877	0.1584	6.3138
0	.0000	1.0000	0.0000	∞

During the World War those of us who were engaged in aerographic work in France found it necessary to use the centesimal system. Since the war, the method has been adopted by the Scandinavian countries.

In nephoscopic determinations, the method has been used with success at Blue Hill. A comparative dial of the compass, the magnetic and the centesimal values is given in figure 7.

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A SINE GALVANOMETER FOR DETERMINING IN ABSOLUTE MEASURE THE HORIZONTAL INTENSITY OF THE EARTH'S MAGNETIC FIELD[1]

By S. J. Barnett

A brief historical statement was made with reference to the measurement of the horizontal intensity of the earth's magnetic field by electrical methods, and a general description of sine and tangent galvanometers was given, with the suggestion of an improvement in the latter. Then followed a detailed description of a new sine galvanometer, constructed, with certain exceptions mentioned below, in the workshop of the Department of Terrestrial Magnetism.

The base of the instrument, including the tripod, circles, etc., was taken from one of Wild's theodolites, constructed by Edelmann, and was much improved by the substitution of non-magnetic parts for parts too magnetic, and by the substitution of electrical illumination of the precision circle for daylight illumination by mirrors.

The magnetometer-box is of pure copper, the damping being chiefly electro-magnetic. The magnet-mirror is a fine disc of chrome steel with optically flat and parallel surfaces, being in fact one of the gages made by the Bureau of Standards. The torsion tube and head are similar to those of the C. I. W. magnetometers. A suspension of phosphor-bronze strip with torsional constant about 0.001 is generally used. The telescope is small but powerful; the scale is ruled to thirds of mm., on white pyralin, with all necessary adjustments. The period of the magnet and the damping, which is adjustable, are such that readings require only a few seconds.

The arrangement of coils is approximately that due to Helmholtz. The spool was machined from white Carrara marble impregnated with paraffin at a temperature near its boiling point. The coils were wound under tension in a single layer in spiral grooves cut with a carbon diamond tool. The wire is pure copper, especially prepared in the research laboratory of the General Electric Co. Each coil is wound in two halves and contains 10 turns with a diameter of approximately 30 cm. and a pitch of approximately 2 mm. The two halves start from the same horizontal plane 180 degrees apart, so that the distance between centers of adjacent wires is approximately 1 mm. The axial distance between the centers of the two coils, or the distance between corresponding turns of the spirals, is approximately 15 cm. The insulation resistance between adjacent wires is very high.

The methods of measuring the diameters and axial distances of the spirals were briefly described and some of the results were given in tables

[1] Abstract of the report presented before the American Geophysical Union, Washington, D. C., April 18, 1921.

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and curves, projected on the screen. The magnetic tests, of three kinds, proving the materials to be satisfactory, were also described.

The theory of the instrument, the method of using it, and the calculation of the error in the constant of the coils due to construction, as well as of the other errors introduced in the measurement of the horizontal intensity, were briefly presented.

It was shown that the errors in reading the circle and the telescope scale when sufficiently large angles are used, and the error in the constant of the coil, were quite negligible; and that the only other error necessary to consider, viz, that introduced in the measurement of the current traversing the coils, can also be made entirely negligible. In consequence, the horizontal intensity of the earth's magnetic field can be determined with an error less than 1 part in 10,000, which more than fulfills all necessary requirements.

The instrumental work, done in the shop of the Department, chiefly by Mr. G. H. Jung, instrument-maker, is highly satisfactory.

The report was closed with acknowledgments.[1]

Department of Terrestrial Magnetism,
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ACTIVITY OF THE EARTH'S MAGNETISM IN 1915

By D. L. Hazard

At the meeting of the International Commission for Terrestrial Magnetism held at Innsbruck in 1905 a resolution was adopted recommending that magnetic observatories classify each day according to its magnetic character as quiet, moderately disturbed, or severely disturbed, using the notation 0, 1, and 2 for this purpose. This recommendation has been adopted by different observatories, one after another, so that now nearly all of the prominent observatories are sending quarterly reports of the magnetic character of days to the Netherlands Meteorological Institute and that institution is publishing them, thus making the data available for all. While this method of characterization is necessarily rough and influenced by the personal equation of the observer, yet the mean of a large number of estimations (between 35 and 40 at the present time) gives a very good idea of the relative magnetic condition of the whole earth from day to day. It does not, however, give an absolute measure of the daily fluctuations of the earth's magnetism nor does it permit a comparison of conditions in different parts of the earth.

In order to determine quantitatively as well as qualitatively the varia-

[1] Since the presentation of this report, the constant of the coil has been redetermined by the use of many additional linear measurements, and two series of simultaneous determinations of the horizontal intensity with the sine galvanometer and the C. I. W. standard magnetometer No. 3 have been made, Messrs. Fleming, Fisk, Peters, Ives, and Barnett participating. The results obtained showed a satisfactory agreement between the two different types of instrument. A complete account of the instrument is given in Vol. IV of the "Researches of the Department of Terrestrial Magnetism."

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bility of the earth's magnetism as a whole, the late Doctor Bidlingmaier devised a method which takes as a measure of the activity of the earth's magnetism its departure from moment to moment from its normal or undisturbed condition. As we have no means of determining as yet what the normal magnetic condition of the earth is, he adopted as the basis for his computations the mean value for the period under discussion; that is, the activity for a day is based on the momentary departures from the mean value for the day. He found that in determining the activity for the day with reference to the mean, the computation could be separated into two parts, first the departures of the hourly mean from the mean for the day, and second the departures of the individual values in each hour from the mean value for that hour. If it later should become desirable to refer to a base value other than the daily mean it would only be necessary to add a third term, depending on the difference between the daily means and the new base value. In each step the mean of the squares of the departures from the base value is computed and this quantity expressed in γ^2 must be divided by 8π to get the activity expressed in terms of the unit 10^{-10} erg/cm^3; that is, the energy per unit volume.

The regular observatory tabulations contain the data for computing the first part provided the mean ordinate for each hour is tabulated, as is now the established practice. Computation of the second part would ordinarily involve the reading of ordinates at frequent intervals for each hour and the computation of the mean of the squares of the differences from the mean value for the hour, this being the so-called hour-integral used in Bidlingmaier's formula in determining that portion of the activity. The amount of work involved would, of course, be prohibitive and he accordingly simplified the process by reading the ordinates for a limited number of hours and using the relation between the hour-integral and the hourly range as a basis for determining the hour-integral for the remaining hours from the hourly range. When the results were plotted with amplitude (half range) as abscissa and hour-integral as ordinate, it was found that the line joining the plotted points formed a smooth curve of parabolic form. While it was found that the values of hour-integral corresponding to a given hourly range differed considerably among themselves, as would naturally be the case because of the varying character of the fluctuation within the period of an hour, yet it was believed that for most purposes, where the results would be combined to obtain mean values, the relation between hourly range and hour-integral derived from a limited number of hours could safely be used in determining the hour-integral for a long period, as for a year.

The parabolic form of the curve representing the relation between amplitude and hour-integral suggested the probability that a linear relation would be found to exist between the square of the amplitude (or range) and the hour-integral. In fact, this must necessarily be the case if the value of activity is to be independent of the sensitivity of the instruments.

At the request of the International Commission for Terrestrial Mag-

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netism a number of observatories undertook to compute the activity of the earth's magnetism according to this method for each day of the year 1915, the Coast and Geodetic Survey carrying out the work for its magnetic observatory at Cheltenham, Maryland. It was suggested by the International Commission that other observatories might safely accept the relation between hourly range and hour-integral as determined by Bidlingmaier for Wilhelmshaven for the year 1911. It was thought best, however, by several observatories, to re-determine this relation in order to be assured that it did not change from place to place. The results show that while for Wilhelmshaven the hour-integral was equal to 11¼ percent of the square of the range, for Cheltenham the factor was 10 percent and for Seddin, near Potsdam, 8¾ percent, and an investigation by Chree, which included the study of the records of the British Antarctic Expedition, showed that while for ordinary latitudes the variation in the factor was not great, conditions were quite different in very high magnetic latitudes.

When the preparation of this paper was undertaken it was expected that it would be possible to compare the results from several observatories, but it was found that only the Seddin results, in addition to those for Cheltenham, were available in printed form.

The geographic positions and mean values of the magnetic elements for 1915 for these two stations are as follows:

Observatory	Cheltenham	Seddin
Latitude	38° 44′ N	52° 23′ N
Longitude	76 50 W	13 04 E
Declination	6 04 W	8 17 W
Dip	70 47 N	66 25 N
Horizontal intensity	19417γ	18726γ
Vertical intensity	55694γ	42898γ
Total intensity	58982γ	46808γ

It will be seen that the two observatories differ very nearly 90° in longitude, and while Seddin is much farther north than Cheltenham, the magnetic dip and intensity are much greater for Cheltenham, the latter station being nearer the magnetic pole.

The activity has been computed for each hour for D, H, and Z at Cheltenham and for X, Y, and Z at Seddin, and these three are combined to get the total activity. The quantities published are the mean value for each day of the year and the hourly means for each month.

In discussing the results of this method of determining the activity three things must be kept in mind. First, since the activity is based on the *square* of the departure from the mean value, a day of very large disturbance will have an overpowering effect on mean values in which it enters. For example, the activity at Cheltenham for June 17 was 1477 and the total for the other 29 days was only 666. Second, Bidlingmaier's conception of activity is different from the usual idea of activity as represented

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by a magnetic disturbance. In the latter case we think only of abnormal variations, whereas he includes all variations, whether systematic (as diurnal variation) or abnormal. Third, as part of the variation of the earth's magnetism is a function of local mean time and part is a function of absolute time, the results for different observatories are not strictly homogeneous. For this reason a more satisfactory agreement between the results for different places may be expected if only that part of the activity is considered which is derived from the hour-integral, as this is to a greater extent independent of local mean time. Even then, however, there is some lack of homogeneity, as for example, in the case of the Seddin tabulations the day begins at Greenwich midnight, whereas for Cheltenham it begins at 5^h G.M.T.

The portion of the activity derived from the hour-integral is much smaller than the part depending on the differences between the mean hourly values and the daily mean, only about one-eighth as great on the average for all days and only one-twenty-fifth for the less disturbed days. The fact that the normal diurnal-variation is such a predominant factor in the total activity as derived by Bidlingmaier's method raises the question whether results of greater value would not be obtained if the diurnal variation was eliminated, at least in part, in computing the activity.

A comparison of the daily mean values of total activity for the two observatories for 1915 shows a general agreement, but with considerable difference in detail, largely because of the third point referred to above. The total activity is on the average about 15 percent greater for Cheltenham than for Seddin, as was to be expected on account of its higher magnetic latitude, but for many days and even for some monthly means the Seddin values are greater.

If only the hour-integral activity is used in the comparison, the agreement is much closer, and when the results are smoothed out by taking five-day means the plotted curves for the two places are almost identical in phase. The agreement is almost as good with the international character numbers, both in phase and relative amplitude, and speaks well for that simple method of determining the degree of disturbance.

A comparison of the monthly means with the relative sun-spot numbers for the same periods shows little evidence of systematic agreement, thus, as pointed out by Schmidt,[1] confirming former experience in comparing these numbers with terrestrial phenomena. In this case the lack of agreement is no doubt partly due to the exaggerated effect on the mean activity for a month of a single day of great disturbance.

As to the diurnal variation of the total activity, the predominant feature is a maximum occurring about noon local mean time. At Cheltenham this feature is modified in the months May to August to form a two-peaked summit with maxima about 10^h and 14^h and a considerable depression between. There is little variation in activity during the night hours. The range of activity is greater in summer than in winter, though, as

[1] *Terrestrial Magnetism*, Sept., 1920.

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already pointed out, the effect of a single day of great disturbance is overpowering. The above characteristics can be traced at once to the features of the diurnal variation of the magnetic elements, the two maxima at Cheltenham corresponding to the minimum horizontal intensity before noon and the maximum west declination after noon.

If we consider only the hour-integral activity, we find very little evidence of system in its diurnal variation in the different months, but there seems to be a tendency toward higher values toward the end of the 24 hours. This is more pronounced for Seddin and corresponds to the distribution of disturbed hours arrived at directly. The effect of a few disturbed hours is so great, however, that it is hardly safe to draw definite conclusions from the results of a single year.

Schmidt discusses some other phases of the activity at Seddin in 1915, in the paper referred to above, but time does not permit going into the matter in greater detail here. He also makes some comparisons with the results of simpler methods of determining the activity.

As a result of the activity computations for 1915, I am of the opinion, which is shared by Schmidt and Chree, that equally valuable results can be obtained by other methods that involve much less time and labor than Bidlingmaier's. His method gives undue weight to days of large disturbance in any combination of hourly values, and the introduction of the term depending principally on the diurnal variation of the earth's magnetism prevents a satisfactory comparison of results at different stations.

Division of Terrestrial Magnetism,
U. S. Coast and Geodetic Survey.

ON MEASURES OF THE EARTH'S MAGNETIC AND ELECTRIC ACTIVITY AND CORRELATIONS WITH SOLAR ACTIVITY

By Louis A. Bauer

When attempting to find correlations between manifestations of the sun's activity and those of the earth's magnetic and electric activity, three points require immediate consideration:

(1) What shall be taken as an adequate measure of the sun's activity with respect to such radiations and emanations as are likely to have an effect upon the magnetic and electric fields of the earth?

(2) What shall be taken as an adequate measure of the earth's magnetic activity, or of the earth's electric activity?

(3) What quantities shall be taken as defining the so-called normal or undisturbed condition of the earth's magnetic field, or of the earth's electric field?

With respect to the first question, we have at present at our disposal the sun-spot numbers, sun-spot areas, flocculi areas, prominences, faculæ, and solar-constant values.

For measures of the earth's magnetic activity, as well as of its electric

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activity, we may use fluctuations in the magnetic and electric quantities, which are more or less periodic in their character, as, for example, the diurnal range or annual range of the magnetic and electric elements. But it is also found that during a magnetic storm and for some time afterwards, the earth's permanent magnetic state, as also possibly its electric state, has been affected. Thus, we have at our disposal both fluctuations about a mean value for a certain interval, and also change in that mean value for a given time. The selection of normal or undisturbed values of any measure taken may be based upon the international list of so-called magnetically-calm or electrically-calm days. Though it must not be overlooked that often the values of the magnetic and electric elements on such days are affected by a peculiar kind of disturbance. In brief it has been found that the magnetic or electric elements on a comparatively undisturbed day are not necessarily normal values. Rather may the values be "normal" which lie intermediate between those for the "quiet" days and those for the days of moderate disturbance.

Every analysis thus far undertaken of any particular magnetic fluctuation indicates that the observed effects are to be ascribed to at least two systems of forces: *E*, an external system consisting most probably of electric currents in the upper regions of the atmosphere; and *I*, an internal system consisting of electric and magnetic systems below the earth's surface. The two systems *E* and *I* are not necessarily related as though *I* were the result of an inductive effect caused by the system *E*. The system *I* would appear rather as a composite system, composed primarily of a direct effect and secondly of an indirect effect which may be related to the fluctuating *E* system. Indications have also been found of the presence of a third system, *C*, consisting of vertical electric currents which apparently pass through the earth's surface, either from the atmosphere or from some internal source. What we observe during a magnetic storm is the combined effect of the three systems, *E*, *I*, and *C*, and this important fact must be borne in mind in endeavoring to find correlations between solar activity and terrestrial activity. It may even happen, as apparently was the case on May 8, 1902, during the eruption of Mont Pelée, that we have a world-wide magnetic fluctuation of internal rather than external origin. Hence, were it feasible, a mathematical analysis should be undertaken first of a magnetic disturbance in order that the effects coming from external sources may be separated from those to be related to internal ones.

The question has also been raised, since at times a magnetic disturbance on the earth apparently precedes some striking manifestation of solar activity, whether there may not be also the possibility of a universe disturbance-system affecting both solar activity and planetary magnetic activity.

As the combined result of my investigations to date, it is found that, in general, the most successful measure of solar activity, of special interest here, is a quantity indicative of the variability of sun-spottedness during a

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given period. For example, instead of taking the sun-spot numbers (N) direct for comparison with magnetic or electric fluctuations, the range (R) in the sun-spot numbers per month, or the average departure (D) of the daily sun-spot numbers from the monthly mean, irrespective of sign, is taken. The R and D quantities are found to run closely parallel to one another; preference was finally given to the D-measure of solar activity as it utilizes all the sun-spot numbers (N) during a month, whereas, the R-measure depends only on two numbers—the maximum and minimum sun-spot numbers of the month. The annual mean values of R and D are furthermore found to run closely parallel with the N-numbers; the monthly values of R and D, however, generally follow a decidedly different course from the N-numbers and exhibit a closer relationship with the measures of the earth's magnetic, or its electric, activity than do the latter (the N's). Some of these relationships between solar activity, terrestrial magnetism, and terrestrial electricity (earth-currents, atmospheric electricity, and polar lights) are shown in figures 1 and 2 and are summarized below.

The adopted measure of the earth's magnetic activity is a quantity, $w = \epsilon Hv$, where H is the horizontal intensity of the earth's magnetic field at the observing station and v, the observed magnetic variation, or range of the magnetic fluctuation; ϵ is a numerical factor. It may be shown theoretically that this value of w, as a first approximation, is representative of the energy-change which the earth's magnetic field experiences during a magnetic variation.

Under certain assumptions it may also be shown that the R and the D measures of solar activity may be regarded, as a first approximation, as representing an energy-change experienced by the sun during a manifestation of activity.

Obtaining similarly, as just described for the sun-spot numbers, R and D measures of solar activity from the solar-constant values (E), which have been observed under the auspices of the Smithsonian Institution at Calama, Chile, during 1919 and 1920, it is found that these latter measures run much more closely parallel with the R and D measures derived from sun-spottedness than do the numbers E and N.

Connections between sun-spot activity, disturbances of the earth's magnetism, earth-currents, and polar lights have been worked out by various investigators. The present investigation shows that there is a fifth natural phenomenon—atmospheric electricity—by which an interesting and suggestive relationship with solar activity is exhibited. Owing to the many disturbances to which the atmospheric-electric elements are subject, as for example during cloudy and rainy weather, it has been more difficult to establish the existence of definite variations of the chief atmospheric-electric elements during the well-known sun-spot cycle of somewhat over 11 years than in the case of magnetic effects, earth-currents, and polar lights. The new results found are based upon atmospheric-electric data obtained chiefly at four European observatories between 1898 and 1919,

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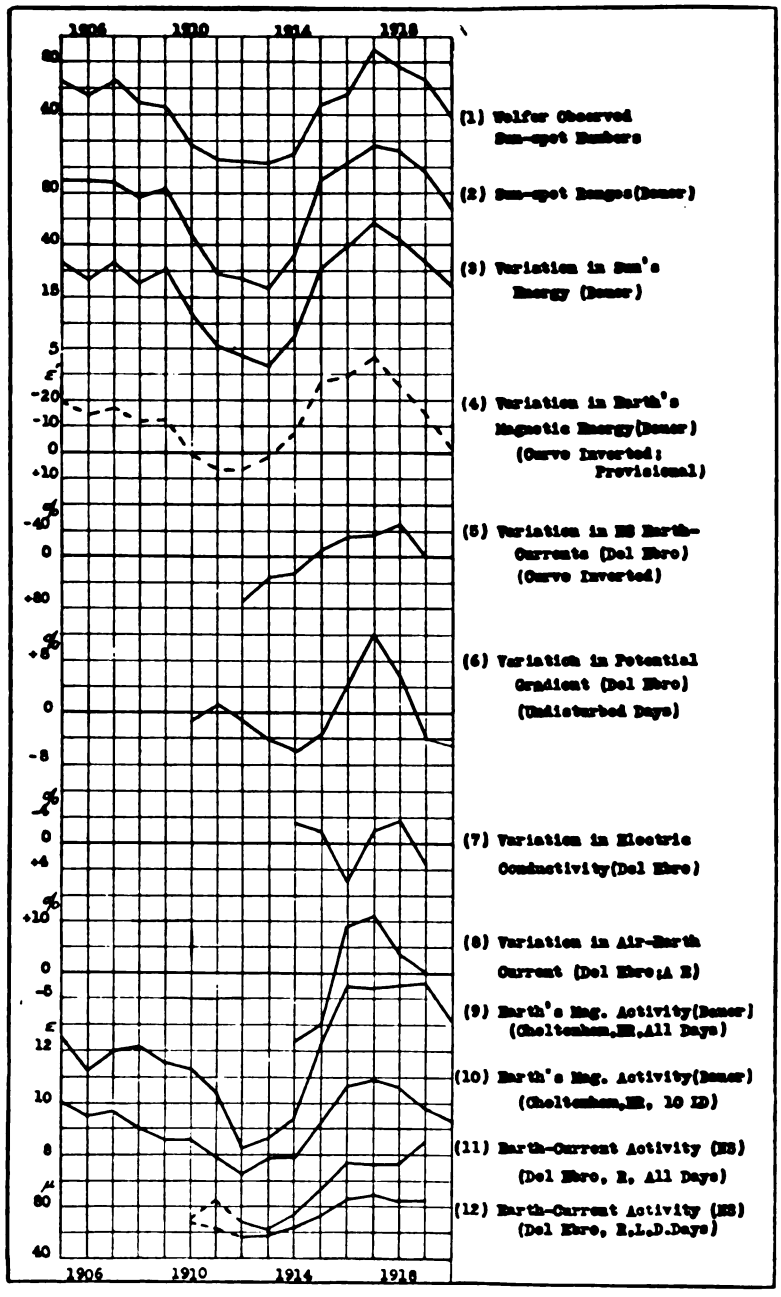
1906
1910
1914
1918
(1) Wolfer Observed Sun-spot Numbers
(2) Sun-spot Ranges(Bemer)
(3) Variation in Sun's Energy (Bemer)
(4) Variation in Earth's Magnetic Energy(Bemer) (Curve Inverted: Provisional)
(5) Variation in NS Earth-Currents (Del Ebro) (Curve Inverted)
(6) Variation in Potential Gradient (Del Ebro) (Undisturbed Days)
(7) Variation in Electric Conductivity(Del Ebro)
(8) Variation in Air-Earth Current (Del Ebro;A E)
(9) Earth's Mag. Activity(Bemer) (Cheltenham,ER,All Days)
(10) Earth's Mag. Activity(Bemer) (Cheltenham,ER, 10 ED)
(11) Earth-Current Activity (NS) (Del Ebro, E, All Days)
(12) Earth-Current Activity (NS) (Del Ebro, E,L.D.Days)

FIG. 1. Variations in solar activity, terrestrial magnetism, atmospheric electricity, and earth-currents during 1905–1920.

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the combined data in the case of the potential-gradient thus covering about two sun-spot cycles. Recent observations on board the *Carnegie* also indicate a decrease in the electric potential-gradient since 1917, when sun-spot activity was at a maximum. A half century ago Quetelet at Brussels and

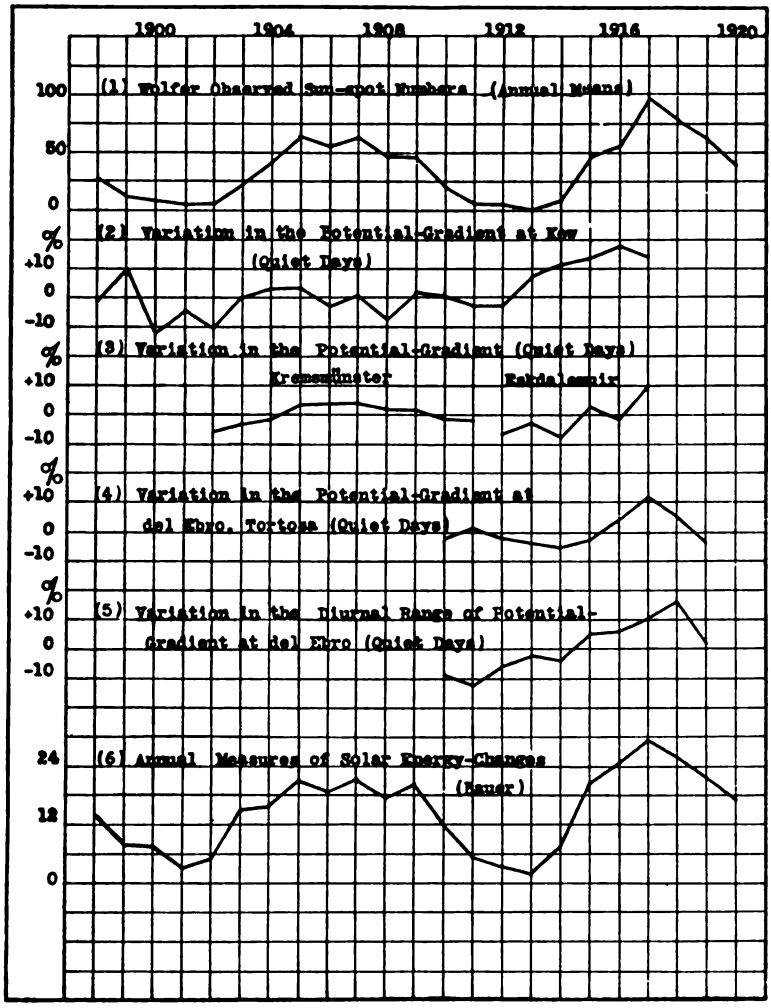

FIG. 2. Variation of the electric-potential gradient and of its diurnal range during sun-spot cycle. (See also Fig. 1.)

Wisclizenus at St. Louis believed that they obtained some definite results showing a variation in the potential-gradient dependent upon sun-spottedness. Owing, however, to the uncertainty of results obtained by the instrumental methods then in use and because of the necessity of thoroughly eliminating the numerous disturbances dependent upon meteorological

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conditions, these previous results have not been accepted, and so modern treatises on atmospheric electricity omit mention of any possible relationship between atmospheric electricity and solar activity.

More complete publication of the results of the investigations here outlined is made in the 1921 volume of the *Journal of Terrestrial Magnetism and Atmospheric Electricity*, pages 33-68 and 113-115.

CHIEF RESULTS

1. The earth's magnetic energy and average intensity of magnetization, as well as the strength of the normal electric currents circulating in the earth's crust, suffer a diminution during increased solar activity. The electric currents induced in the earth during periods of increased solar activity are in general reversed in direction to the normal currents, the strength of these superposed currents increasing with increased solar activity.

2. The diurnal range of the strength of earth-currents, as in the case of the diurnal range of the earth's magnetic elements, increases with increased solar activity; at time of maximum activity the range, as shown by the observations at the Observatorio del Ebro, Tortosa, Spain, during the period 1910–1919, was about 50 percent higher than at the time of minimum solar activity.

3. The magnetic effect running a concomitant course with the solar-activity cycle is retarded, on the average, about one year so that there is a residual, or an acyclic, effect at the end of the cycle. The actual amount of retardation, in general, increases with intensity of the sun's activity or energy. This lag in the magnetic effect may be accounted for by the fact that the electric currents generated inside the earth during magnetic storms and magnetic variations continue for some time after the apparent cessation or diminution of solar activity, or after the period of the variation experienced. The same lag is shown by polar-light frequencies at times of maximum solar activity.

4. On fine-weather, or electrically-calm, days the atmospheric potential-gradient, or the deduced negative charge on the surface of the earth, increases with increased solar activity, the range in the variation between minimum and maximum solar activity being about 20 percent. The electric conductivity of the atmosphere, on the other hand, shows but little, if any, systematic variation during the solar cycle. Accordingly, since the vertical conduction-current of atmospheric electricity is derived from the product of the potential-gradient and the electric conductivity, it is found that this vertical current also increases in strength with increased solar activity. It would thus appear that atmospheric electricity, like terrestrial magnetism, is controlled by cosmic factors. The results derived here may have an important bearing upon theories of atmospheric electricity.

5. The diurnal range of the electric potential-gradient as deduced from the observations on the electrically-calm days, made at the Observatorio

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del Ebro, Tortosa, Spain, 1910–1919, is found to increase with solar activity; the minimum occurred in 1911 and the maximum in 1917, whereas the sun-spot minimum occurred in 1912 and the maximum in 1917. The range between minimum and maximum diurnal range is about 25 percent. (It appears probable that the same fact just stated for the potential-gradient will also be found true for the vertical conduction-current.)

Department of Terrestrial Magnetism,
Carnegie Institution of Washington.

THE PENETRATING RADIATION AND ITS BEARING UPON THE EARTH'S ELECTRIC FIELD[1]

By W. F. G. Swann

The paper was devoted largely to a description of certain investigations on the penetrating radiation in progress at the University of Minnesota, under the author's direction. It opened with a brief review of the status of our knowledge with regard to the penetrating radiation.

In a hermetically sealed zinc vessel freed from radioactive air, ions are produced at a rate of about 8 or 9 per c.c. per second over the land. According to the computations of A. S. Eve, the normal gamma-ray radiation from the atmosphere is capable of accounting for about 0.06 ion per c.c. per second, while that from the soil will account for 1.6 ion per c.c. per second, making in all 1.7 ions. On account of the secondary ionization resulting from electrons emitted from the walls of the vessel by the primary radiation, this value becomes increased to about 2.5 ions in the case of vessels of the size ordinarily used. If this value be subtracted from the 8.5 ions per c.c. per second found over land, there remains about 6 ions per c.c. per second attributable to causes which are not directly obvious, and this corresponds roughly to the ionization (4 to 6 ions per c.c. per second) observed over the ocean.

The results of several investigators seem to indicate that, in vessels surrounded by thicknesses of water sufficient to absorb practically all gamma-ray radiation of the ordinary type, the ionization does not become reduced greatly below that found over the great oceans, nor does it diminish appreciably with increasing thickness of water, so that, if this ionization is due to an external radiation, this radiation must be of an extremely penetrating type as compared with ordinary gamma-radiation. By using a vessel of ice, in order to be as free as possible from radioactive contamination, McLennan obtained a value as low as 2.6 ions per c.c. per second over Lake Ontario, and inclines to the view that even this small residual is attributable to lack of complete purity of the ice. On the other hand, results obtained by Kolhörster in balloon ascents up to 9.5 kilometers show an increase to about 80 ions per c.c. per second at this altitude, in a her-

[1] Abstract of the paper presented at the annual meeting of the American Geophysical Union, Washington, D. C., April 18, 1921.

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metically sealed, light, tight vessel; moreover, the rate at which the apparent ionization increases with altitude in the neighborhood of 9 kilometers is such as to suggest that at altitudes but slightly greater, the ionization might attain enormous values. The validity of Kolhörster's results has been questioned by C. H. Kunsman in view of possible complications resulting from the effect of the low temperature on the insulating material used; if, however, they should be substantiated, they afford one of the most convincing evidences that one could wish as to the true cosmic nature of part at least of the so-called penetrating radiation. By the employment of precautions such as to prevent all uncertainty as regards leakage, and by the use of small pilot balloons, the writer is at present endeavoring to extend the observations of Kolhörster to greater altitudes.

VARIATION OF RESIDUAL IONIZATION WITH PRESSURE

The study of the variation of the residual ionization with pressure has a very important bearing upon the origin of that ionization. If the residual ionization were due to alpha-rays emitted from the walls of the vessel, it would show practically no increase with pressure in the case of a vessel whose linear dimensions were of an order of magnitude greater than the range of the alpha-particles. Analagous remarks hold for the case of soft beta-rays emitted from the walls. In the case of a radiation of cosmical origin there are three possibilities, viz, (1) a direct ionization by the primary radiation, (2) ionization by slowly moving electrons emitted from the gas by the primary radiation, (3) ionization by rapidly moving electrons emitted from the gas by the primary radiation, the penetrating power of the electrons being such as to enable them to go right across the vessel at atmospheric pressure. A fourth possibility resulting from emission of electrons from the walls of the vessel by the primary rays, is indistinguishable from a corresponding emission resulting from radioactive contamination. Ionization of the first and second type would increase proportionally with the pressure until the pressure attained was so high that the primary radiation itself became appreciably absorbed in passing through the vessel. Effects resulting from the third type of ionization require more detailed consideration.

At each point in the gas there will be a definite value of what we shall call the ionizing intensity I, i.e., the number of ions which would be produced per c.c. per second in an element of gas at *atmospheric pressure* placed at the point in question. For the purpose of this definition, we may suppose the element of gas to be contained in a non-absorbing capsule, since it is of course not implied that the whole of the gas is at atmospheric pressure. The number of ions produced per c.c. per second in the gas at some point O where the pressure is p will be Ip.

Let us consider an element of volume $ds\ dr$, situated at a point P at a distance r from O in some definite direction, dr being element of radius vector, and ds being element of cross section of an elementary cone of

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solid angle $d\omega$ drawn from O to P. The contribution of the element of volume to the value of I at O is

$$\Delta I = \frac{pN}{r^2} f(pr)\, ds\, dr$$

where, assuming the secondary radiation originating within an element of volume to be proportional to the pressure therein, $pN\, ds\, dr$ is the secondary ionization intensity at unit distance from P in the direction PO, on the basis of no absorption, and $f(pr)$ is a factor inserted to take account of the absorption in passing from P to O, and also of the variation of the ionizing efficiency along the path of the ionizing agent. By writing $f(pr)$ instead of $f(r)$, we imply that the diminution of the ionizing intensity per unit distance (apart from spreading) is proportional to the number of molecules per c.c. In terms of the solid angle $d\omega$ above referred to we have:

$$\Delta I = N f(pr)\, p\, dr\, d\omega$$

If we should now increase the pressure from p to p_1, and diminish r to r_1 so that $pr = p_1 r_1$, and dr to dr_1 so that $p dr = p_1 dr_1$, the new element of volume contained between the radii r_1 and $(r_1 + dr_1)$ in the cone $d\omega$ will make the same contribution to the ionizing intensity at O as did the old element of volume comprised between r and $(r + dr)$. The sum total of all the elements of volume in the vessel, corresponding to the lower pressure will, however, correspond to a sum total of elements of volume which, at the higher pressure, do not fill the vessel. Hence, the actual ionizing intensity at O will be greater at the higher pressure than at the lower pressure. Since q, the number of ions produced per c.c. per second at O, is obtained by multiplying I by the pressure p in atmospheres, we see that the increase in q, per atmosphere increase, should itself increase with the pressure. We may extend this statement so as to include in q the ionization due to the direct action of the external radiation, since this increases proportionally with the pressure. Thus, the actual ionization in the vessel, due to primary and secondary emission from the gas, will be less at one atmosphere than at any higher pressure. If then, the ionization-pressure curve should show a very small increase of ionization per atmosphere increase at high pressures, we know from the above that such increase per atmosphere is nevertheless greater [1] than the portion of the ionization due to primary and secondary action in the gas within the vessel at one atmosphere. We may infer that any greater ionization found at atmospheric pressure is to be attributed to radiation from the walls of the vessel; this radiation, owing to its absorption at the higher pressures, results in a diminishing rate of increase of ionization with pres-

[1] It would not be quite safe to extend this argument to imply that the ionization here referred to was necessarily greater than the true natural ionization in the open air, since a portion of the ionization in a volume of the external air occupying the space of the vessel would result from secondary radiations originating outside of that volume.

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sure. The foregoing discussion has been made for the case where the primary radiation is so penetrating as to be but little absorbed in passing through the gas in the vessel, even at the higher pressures, this being the case which is of interest in discussing the action of a radiation whose degree of penetration is comparable with that attributed to the cosmical penetrating-radiation.

Experiments on the variation of the residual ionization with pressure have been made by several investigators, the most recent being those made under the writer's direction, by Dr. K. M. Downey and by Mr. H. Fruth. The main feature of the experiments of the latter investigators lay in the use of a comparatively large vessel (a sphere one foot in diameter), and the employment of certain special devices to insure freedom from errors due to leakage and lack of constancy of the batteries. Dr. Downey's observations extended in the first instance up to 20 atmospheres, giving over this range a practically perfect linear variation with the pressure and an increase of ionization of about 1.2 ions per c.c. per atmosphere increase. On extending the observations to higher pressures, it was found that the linear relation ceased to hold in the neighborhood of about 27 atmospheres, and the curves finally became parallel to the pressure axis at pressures above 46 atmospheres. If one were to accept this parallelism without reservation, he would be forced to conclude that the portion of the ionization within the vessel which was attributable to the direct or indirect action of the radiation on the gas was immeasurably small.

Mr. Fruth's observations have been made for air, oxygen, and nitrogen up to pressures of 75 atmospheres, and for carbon-dioxide up to its liquefying pressure, with sensibly the same results for all the gases used. While his curves do not attain as complete a parallelism with the pressure axis as do those of Dr. Downey, they correspond to an increase per atmosphere of less than 0.75 ion per c.c. per second at the higher pressures.[1] It is worthy of note that the presence of radium-emanation in the gas would tend to increase the slope of the ionization-pressure curves. The normal emanation-content of the atmosphere is such as to produce about 2.3 ions per c.c. per second. Each additional atmosphere of air would, of course, carry with it its emanation-content, so that the increase per atmosphere for normal air resulting from the emanation-content alone would amount to 2.3 ions per c.c. per second per atmosphere increase. It is therefore necessary to carefully age the air before use. Recalling that the emanation activity dies to half value in 3.85 days, it will be readily seen that in the case of air 3 weeks old the effect of the emanation would become reduced to a negligible amount. In some of Dr. Downey's observations the air was aged for a month before use.

In experiments of this kind it is of the utmost importance to insure complete saturation, and this matter was consequently tested very care-

[1] Since this was written Mr. Fruth has found complete parallelism for air, oxygen, and carbon dioxide for pressures above 52 atmospheres, when the gases are perfectly dry and dust-free.

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fully, the voltages used being considerably higher than those at which experiment showed saturation to have been attained at the higher pressures. One element of uncertainty not usually considered in relation to the attainment of saturation must be here referred to. It pertains to the effect of dust nuclei. Such nuclei could theoretically cause a departure from a saturation which could not be reduced beyond a certain minimum however great the field might be, since increase of the field intensity could not reduce beyond a certain limit the probability of an ion's encounter with a dust nucleus during its passage across the vessel. Departure from saturation due to such a cause would not show up by the failure to attain apparent saturation with increasing field, and it would increase, moreover, with increase of the amount of gas (and consequently of dust nuclei) in the vessel. The comparatively good agreement between the results of Dr. Downey and those of Mr. Fruth, and the agreement of the various results of the latter investigator among themselves, suggest, however, that dust did not play an important rôle in the experiments, particularly when one remembers that the various experiments corresponded to different samples of gas, samples which had undergone, moreover, entirely different treatments. However, it is planned to make a very careful investigation of the effect of dust in this connection; for, if the experiments of Dr. Downey and of Mr. Fruth represent a primary phenomenon, not explicable by subsidiary considerations of this kind, they carry with them the very remarkable conclusion that, of the ionization observed in a vessel at atmospheric pressure and ordinarily attributed to a penetrating radiation, less (and probably considerably less) than one ion per c.c. per second is to be accounted for as having its origin in a direct action of the primary radiation on the gas or in the action of a secondary radiation emitted from the gas by the primary radiation.

EXPERIMENTS ON THE DIRECTION OF THE PENETRATING RADIATION

An important light would be thrown upon the origin of the penetrating radiation if it could be shown to partake of a directive character. Experiments on this matter were originally made by Cook and by Wood, who interposed screens between the apparatus and its surroundings at various orientations. The experiments were inconclusive, but, as far as they went, seemed to indicate that the radiation came equally from all directions. A method of this kind is very seriously affected by lack of constancy of the residual ionization itself during the various experiments between which comparisons are subsequently made, and, for this reason, some experiments were undertaken by Miss J. Herrick under the writer's direction with the object of eliminating the main causes of uncertainty in the earlier experiments of Cook and Wood. The method used by Miss Herrick depends upon the fact that if gamma-rays pass through a thin sheet of metal, the ionizing electrons emitted from the side at which the rays enter differ as regards their number and speed from those which are ejected from the

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side at which the gamma-radiation leaves. If the penetrating radiation is of a gamma-ray type, it should show similar characteristics. The ratio of the subsequent ionization resulting from the incidence of gamma-rays on a surface to that resulting from the emergence of gamma-rays from the surface depends upon the material of the surface. The apparatus used consisted of two similar cylinders mounted with their axes in the same horizontal line. One semi-circular half of each cylinder was made of lead, and the other half was made of aluminum. The cylinders were provided with central rods which were connected to each other and to the insulated quadrant of an electrometer. By placing potentials of plus fifty and minus fifty volts respectively on the cylinders, the ionization currents in the gas could be caused to feed into the electrometer in such a way as to almost completely compensate. Several precautions to avoid leakage, and errors due to fluctuation in the potentials of the batteries were taken, the details of which it will be unnecessary to describe.

To fix our ideas, suppose that an excess of gamma-radiation comes from above, and that in the case of one of the cylinders the lead half is uppermost. Then, as far as ionization due to the emission of electrons from the wall of the vessel is concerned, the ionization in the vessel in question (or rather the portion of it due to the excess of radiation coming from above) will be due to the emergence radiation from the lead, and the incidence radiation from the aluminum. An alteration of the effect should consequently be produced by rotating the cylinder through 180 degrees, while the other cylinder is left untouched, its function being simply to act as a compensator for the purpose of minimizing effects resulting from an actual variation in the conditions during the experiment. Without here entering into details, it will be seen that it would be possible to obtain a comparison between the radiation coming in different directions and the total radiation entering the vessel in so far as the ionization was due to the electrons emitted from the walls of the vessel and in so far as one assumed the penetrating radiation to partake of the nature of a hard gamma-radiation as regards the difference between the incidence and emergence effects in the case of the metals used.

The first experiments performed by Miss Herrick in the laboratory of the physics building showed marked changes on rotating one of the cylinders, and by plotting a polar diagram representing the ionization due to radiation coming from the various directions it became possible to locate small quantities of radium in different parts of the building. The polar diagram, moreover, showed a hump indicating an excess of radiation coming from above. The apparatus was next moved to the astronomical observatory, where there was no radioactive material, and experiments again gave an indication of an excess radiation from above. In order to be free from all possibility of radioactive contamination, the writer next set the apparatus up in the attic of his house, and carried on observations over a period of 6 weeks, the observations being taken between the same hours each day. The attic of a dwelling house is not the most ideal situa-

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tion for a quadrant electrometer, but on plotting the results for the various experiments there was again decided evidence of an excess radiation in the downward direction. The magnitude of the excess was such that, when the vessel was turned in the most favorable direction, the ionization was about 9 percent greater than the average, a result in comparatively good agreement with the observations of Miss Herrick made on the university campus.

These experiments are only cited as of a preliminary nature, for there are certain sources of complication which must be removed before a cosmical interpretation may be made of the results. Thus, the potential-gradient in the atmosphere will deposit active material from the atmosphere on the roof of the building in which experiments are made. A simple calculation will show that the amount of such deposition may well be enough to seriously affect experiments of the kind described above. Similar remarks apply to the effect of radioactive material in the soil itself, and that deposited on the surface of the soil by the atmospheric potential-gradient. It is planned to continue the observations under conditions which, it is hoped, will eliminate these causes of uncertainty.

THE EARTH'S PENETRATING RADIATION AND THE ORIGIN OF THE EARTH'S CHARGE

In 1915, the writer proposed a theory of the origin of the earth's charge based on the assumption that high speed electrons were shot into the earth from the atmosphere as a result of a very slight radioactivity of the atmosphere itself, or as a result of the breaking up of the emanation normally in the atmosphere. If one assumes that an electron of sufficiently high speed can have a range as great as 5 kilometers in the atmosphere, it is only necessary to postulate the emission of one such high speed corpuscle per c.c. in the downward direction, each 100 seconds in order to account for the maintenance of the earth's charge. Or, viewed from another standpoint, since we know that about 5 pairs of ions are formed per c.c. per second in the atmosphere, it is only necessary to suppose that in the case of one out of every 500 pairs of ions formed a high speed corpuscle of the above kind is emitted. The theory of passage of electrons through matter is not at all inconsistent with the postulation of great ranges such as those required by the theory; however, in 1917 Swann[1] put forward another theory in which the expulsion of the electrons from the atoms of air is brought about by the penetrating radiation from above, the hard nature of this radiation resulting in its emitting electrons from the air molecules almost exclusively in the downward direction. Under the influence of the electronic bombardment, the earth would charge up until the conduction current back to the atmosphere just sufficed to balance the effect. It appeared that if one assumed as many as 3 corpuscles to be emitted per c.c. per second from the atmosphere, it would only be necessary to postulate a range of penetration of about 9 meters in order to

[1] *Phys. Rev.*, 9, 555-557, 1917.

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account for the maintenance of the earth's charge. As pointed out by the writer at the time, the chief difficulty facing a theory of this kind is the explanation of why the swiftly moving corpuscles do not produce, in the atmosphere, a much greater ionization than is observed. Difficulties of this kind assume a much less formidable aspect, however, when viewed in the light of modern views as to the properties of swiftly moving electrons. In 1918, v. Schweidler independently put forward the second of the above theories, and described an experiment carried out with the object of testing it. The aim of this experiment was the endeavor to observe a charging effect in a thick piece of metal as a result of corpuscles entering it, the piece of metal being surrounded by a shield from which it was insulated. Failure to observe any charging effect caused v. Schweidler to conclude that the replenishment of the earth's charge could not be brought about by a corpuscular radiation of the type discussed. As a matter of fact, the writer had performed an experiment somewhat similar to v. Schweidler's experiment in 1915, in connection with his earlier theory of corpuscular charging. In this experiment an earthed vessel surrounded an insulated hollow cylinder connected to an electrometer. The rate of rise of potential was noted, and a solid copper bar was then inserted in the hollow cylinder, the rate of rise being then again noted. By this device of performing two experiments in which the surfaces exposed were the same, surface effects were eliminated. As in v. Schweidler's experiment, no certain charging effect was observed; and, while this weighed against the former of the theories above referred to, it was not felt that it formed so weighty an argument against the latter, for on that theory it might result that the penetrating radiation would shoot as many electrons out of the bottom of the cylinder as it shot in at the top, except for the absorption of the penetrating radiation itself within the cylinder. In other words, it is the coefficient of absorption of the penetrating radiation in the cylinder rather than the coefficient of absorption of the corpuscles which is of importance. In a recent paper,[1] R. Seeliger discusses the origin of the earth's charge. He considers v. Schweidler's experiment as conclusive evidence against any theory which postulates a corpuscular replenishment at all parts of the earth, but raises the question as to whether a corpuscular replenishment may not take place in certain limited areas, in polar regions for example. It is to be observed that any assumption of this kind invites, in their most serious form, difficulties associated with the ionization which might be expected to result from a passage of the corpuscles through the atmosphere. For a concentration of the corpuscular current in a limited region would result in greatly increased ionization in that region, and on the assumption that a corpuscle produces 50 ions per centimeter of its path and that the coefficient of recombination of ions is 1.6×10^{-6}, it can readily be shown that, unless the area of precipitation were more than one thousandth of the area of the earth, the conductivity produced in the air in the region of precipitation would be so great that, for a potential gradient of 150 volts per meter, one would calculate

[1] *Annalen der Physik*, 63, 464-481.

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for this region alone a total conduction current greater than the corpuscular current. In other words, there is a lower limit to the value which one may assume for the region of precipitation. Thus the avoidance of difficulties concerned with the failure to directly measure a corpuscular current, by relegating that current to regions where experiments have not been made, does not avoid what is perhaps one of the most serious difficulties confronting any corpuscular theory, that of reconciling the comparatively small ionization of the atmosphere with the passage through it of about 1500 high speed corpuscles per square centimeter per second.

THE CONDUCTIVITY OF THE UPPER ATMOSPHERE

The paper concluded with a reference to the importance of a knowledge of the conductivity of the upper atmosphere in relation to the origin of the earth's charge and allied phenomena, and the author described an experiment in progress at the University of Minnesota designed with the object of measuring the distance of the supposed conducting layer by measuring the time taken by wireless waves to reach that layer and return.

RECENT RESULTS DERIVED FROM THE DIURNAL-VARIATION OBSERVATIONS OF THE ATMOSPHERIC-ELECTRIC POTENTIAL-GRADIENT ON BOARD THE *CARNEGIE* [1]

By S. J. Mauchly

The Department of Terrestrial Magnetism, in accordance with its director's plans, has for many years been making not only magnetic but also atmospheric-electric observations aboard its survey vessel, the *Carnegie*. It is thus contributing the chief data for mapping both the earth's magnetic field and its electric field. Furthermore, since 1915 numerous observations have been made aboard the *Carnegie* to determine the nature and magnitude of the changes in the electric condition of the atmosphere which take place during a 24-hour cycle.

For the *potential-gradient* the general procedure in the diurnal-variation observations is to make a set of 20 observations during each of 24 consecutive hours. The observations for such a set require about 20 minutes and their mean value is referred to the mean time for the set. From deductions based on the observations made prior to April, 1916, it appeared that the diurnal variation of the potential-gradient over the oceans probably did not differ much from that which has been found at many land stations; that is, they indicated two rather pronounced maxima and two minima during a 24-hour period.[2] However, very few data were

[1] Preliminary report presented before the American Geophysical Union, with amplifications.

[2] "Researches of the Department of Terrestrial Magnetism," Vol. III, pp. 416–420, Washington (1917).

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available from oceans other than the Pacific, and as pointed out in the report just cited, a large percentage was derived from series of observations which were terminated by the advent of unfavorable weather. It should also be noted in passing that Swann[1] a year later in discussing

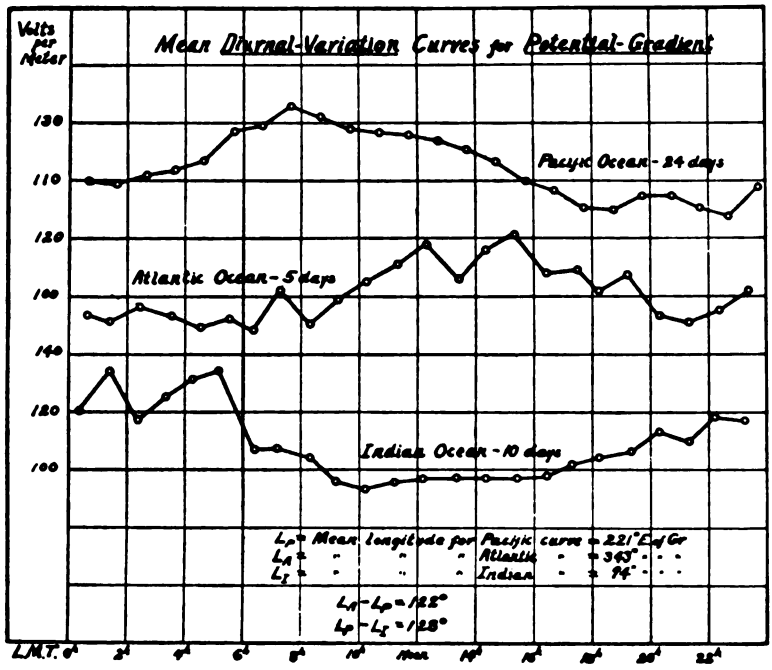

FIG. 3. Diurnal variation of electric potential-gradient on the oceans, plotted according to Local Mean Time.

the results of the observations for the year ending February 20, 1917, states that "the effect of the 12-hour Fourier wave is less important in the present curves than in those already published."

The largely increased amount of material which has accumulated since 1915 makes it now possible to reject nearly all data corresponding to less than a 24-hour series and still have 45 practically complete 24-hour series available. The data for each series, therefore, correspond to an actually occurring sequence of phenomena, and the mean results are free from the errors which would result from combining the results of partial series of observations.

Of the 45 diurnal-variation series referred to, 30 were made in the Pacific, 5 in the Atlantic, and 10 in the Indian Ocean; the combined data represent about half the earth's surface. The means corresponding to

[1] W. F. G. Swann. "Supplementary report on atmospheric-electric observations made aboard the *Carnegie* from May 17, 1916, to March 2, 1917," in "Annual Report of the Director of the Department of Terrestrial Magnetism" for the year 1917. Year Book of the Carnegie Institution of Washington, 1917, p. 282.

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the separate oceans, as derived from 39 series, are represented in figure 3. They show: (1) That the mean diurnal-variation curves for the Pacific, Atlantic, and Indian oceans are similar in form; (2) that the principal component of the variation consists of a 24-hour wave, and (3) that the times of occurrence of the chief phases of this wave, when referred to

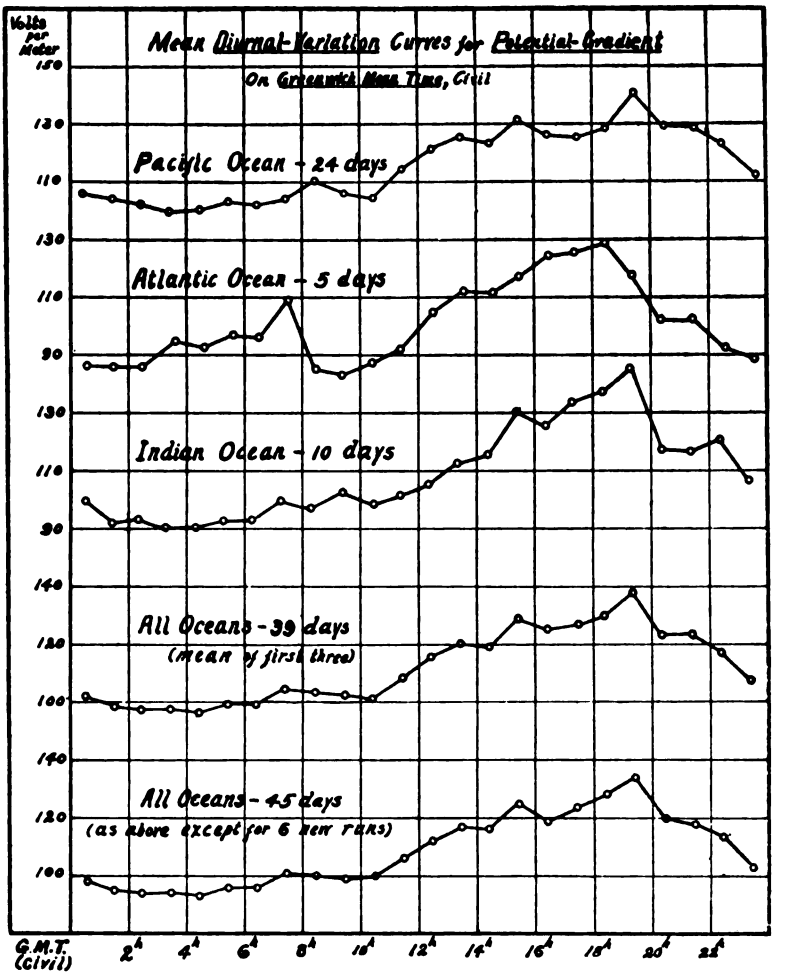
Volts per Meter
Mean Diurnal-Variation Curves for Potential-Gradient
On Greenwich Mean Time, Civil
Pacific Ocean - 24 days
Atlantic Ocean - 5 days
Indian Ocean - 10 days
All Oceans - 39 days
(mean of first three)
All Oceans - 45 days
(as above except for 6 new runs)
G.M.T. (civil)
2h 4h 6h 8h 10h 12h 14h 16h 18h 20h 22h

FIG. 4. Diurnal variation of electric potential-gradient on the oceans, plotted according to Greenwich Mean Time.

local time, differ for the several oceans by amounts which correspond approximately to the differences between the respective mean longitudes, for the several oceans, of all the points at which observations were made.

Since the curves of figure 3 suggest the simultaneous occurrence of maximum (or of minimum) phase over all three oceans, it was decided

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to refer the results of each series of observations to Greenwich Mean Time (civil), and recompute the means for the separate oceans on this basis. The results are shown in figure 4, together with a curve which includes the data from 6 recent series received from the vessel after the curves in figure 3 had been prepared. The differences between the several curves of figure 4 are of course not to be thought of as representative of separate characteristics, since the smoothness of the respective curves is seen to be closely related to the number of component series.

The curves of figure 4 show a decided similarity to land results for high latitudes and also to many of the winter curves obtained in ordinary latitudes. Indeed, if differences in local mean time are taken into account, it appears that for many land stations at which the single diurnal wave predominates, there is approximate simultaneity as to the time of occurrence of maximum (likewise, of minimum), and this at a time which is in general agreement with what is indicated by the curves of figure 4. For the summer, however, as is well known, most land stations show, in addition to the 24-hour wave, a decided secondary wave which seems to occur in general at about the same local mean time at different stations.

The minimum value of the potential-gradient, according to figure 4, occurs at about 4^h A.M., G.M.T., and in view of the fact that for observatories in western and central Europe the difference between local and Greenwich time is not great, this may account for the fact that various authorities have assumed the occurrence of the principal minimum at about 4^h A.M., local time, to be a rather general characteristic for most stations. It is also significant to note that Mache and v. Schweidler [1] long ago pointed out that the phase angle of the 24-hour wave varied greatly from station to station while the phase angle of the 12-hour wave was approximately the same for nearly all stations. Although the phase angles of the 24-hour Fourier waves for the European stations show among themselves very much greater differences than can be accounted for by the rather small differences in longitude, it must be borne in mind that the results of harmonic analyses are dependent upon local meteorological and cultural, and sometimes topographical and instrumental, factors as well as upon any general characteristics which the potential-gradient may possess.

In the present investigation no account has been taken of possible changes in the characteristics of the diurnal variation with latitude and with time of year, except to ascertain that the preponderance of the 24-hour wave and the approximate progress on a universal-time basis seem to hold throughout the year and for wide ranges of latitude. The present results are, therefore, to be considered as provisional and representing only a general yearly average. In fact, investigations under way show that considerable modification in detail is to be expected as more observational material becomes available. The data from 45 practically

[1] H. Mache und E. v. Schweidler, "Die Atmosphärische Elektrizität," p. 27, Braunschweig, 1909.

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complete series of diurnal-variation observations aboard the *Carnegie*, representing a general distribution over most of the accessible ocean-areas indicate, therefore, as a preliminary result, that ***the chief component of the diurnal variation of the potential-gradient over the major portion of the earth (especially the oceans) is a wave of 24-hour period which occurs approximately simultaneously in all localities.***

A fact of considerable interest is that the diurnal-variation curves for the potential-gradient derived from the *Carnegie* observations are very similar to curves which represent the relative frequencies of the Aurora Borealis, as observed at several European stations, and also to curves representing the diurnal distribution of certain classes of magnetic disturbances, when all are referred to the same time-basis. It may also be pointed out that owing to the non-coincidence of the earth's magnetic axis with its axis of rotation, the time of daily potential-gradient maximum, as indicated by the ocean curves, corresponds approximately to the time when the earth's north magnetic pole, for example, is nearest to the sun, while the daily minimum occurs, in a general way, when this pole is farthest from the sun. The actual times of maximum and minimum, however, appear to depend upon the positions of *both* magnetic poles and the fact that their longitude difference is not 180°. These correlations appear to support the assumptions of various investigators that the earth's electric charge and resultant field may be very intimately related to an electric radiation from the sun. The best evidence as to the extent of this support will probably result from a study of the details of the diurnal-variation curves corresponding to various positions of the earth in its orbit. Reductions with this end in view are under way and it is hoped that sufficient data will soon be available to yield some information on this point.

The making of diurnal-variation observations in atmospheric electricity by eye readings is always a burdensome procedure; the carrying on of such work aboard a vessel is not only arduous but also difficult. In this connection the utmost credit is due the several commanders of the *Carnegie*, during her various cruises, and to all the observers who participated in the observational work.

I am indebted to the director, Dr. L. A. Bauer, for his constant interest in and encouragement of the work in hand, and for a suggestion of the possibility of finding in the asymmetry of the earth's magnetic field an explanation of the observed diurnal variation on a universal-time basis. I am also greatly under obligations to the members of the Department of Terrestrial Magnetism who assisted in the reduction of the observational data, especially to Dr. G. R. Wait, both for valuable assistance and helpful suggestions.

The full publication of the observational data and discussion of results will be deferred until after the completion of the present cruise of the *Carnegie*.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington.

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SUGGESTIONS RELATIVE TO THE APPLICATION OF MATHEMATICAL METHODS TO CERTAIN BASIC PROBLEMS OF DYNAMIC OCEANOGRAPHY

By G. F. McEwen

Investigations of the ocean have generally been carried on by geographers and geologists, oftentimes incidentally to those of other divisions of these extensive fields of science. Accordingly, qualitative methods so characteristic of geography and geology have been widely used in oceanographic investigations. Such qualitative methods and the empirical treatment of quantitative field observations have been very suggestive, have stimulated interest, and led to certain broad generalizations that are essentially correct. However, there has been a tendency toward rather loose reasoning and lack of consideration of established quantitative principles of physics, which has resulted in certain erroneous conclusions.

Must we admit that the complexity of such geophysical phenomena renders careful reasoning and quantitative treatment impossible of attainment? Probably many would at first answer yes, but let us consider the matter further before expressing an opinion. Within the past fifty years a few scientists have undertaken, by means of a definite formulation of specific problems, to apply mathematics to ocean data, and thus to contribute to a system of demonstrable principles applicable, in general, to all similar cases; and attention has been increasingly directed to this type of research. Important advances have thus been made, and serious errors in certain former conclusions have been discovered, although, especially in some of the earlier attempts at mathematical applications, significant errors arose from incorrect assumptions and failure to appreciate important attributes of such "field," or natural problems. At first, men accustomed to the problems of laboratory physics attempted to deduce physical laws of the sea from results of laboratory studies, and certain preconceived assumptions regarding oceanic conditions. They also worked under the disadvantage of having very inadequate data. As more accurate and exhaustive field data accumulated, attention was directed more to interpreting and coordinating field observations rather than to depending on the speculative and unsound method of imposing on the sea purely theoretical laws deduced from laboratory researches.

Mohn's pioneer investigation of 1887,[1] based on the deduction of the changes in form of the surface that would give rise to currents actually produced by winds, variation in barometric pressure, and specific gravity, was a great advance beyond earlier attempts at a precise treatment of ocean data, and doubtless contributed greatly to the development of the more satisfactory methods of today. Among the later results thus worked

[1] Mohn, H. 1887. The Norwegian North Atlantic expedition, 1876–1878: The North Sea, its depths, temperature and circulation. (Christiania, Grondahl), 212 pp., 48 pls.

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out are Ekman's [1] hydrodynamical theory of oceanic circulation, which pertains especially to wind-driven currents, and was undertaken at Nansen's [2] suggestion; and Bjerknes's [3] convection theory which pertains especially to the determination of ocean currents due to differences in specify gravity. Later his pupil, Sandström,[4] devised a much more rapid and accurate method of computing such currents.

The Norwegian investigator, Jacobsen,[5] in certain more recent quantitative investigations pertaining to the Atlantic near Denmark, obtained encouraging results by giving special attention to the alternating convective motion of small masses of the water, or to the "mixing phenomena," as he called it. His researches afford strong evidence in support of the idea suggested by earlier qualitative studies, that in lakes and oceans, very small or elementary masses of the water are moving at random in a manner somewhat analogous to the motion of molecules in a gas, except that the direction of motion in large bodies of water is mainly vertical, although the resultant vertical flow may ze zero. This phenomenon of the interchange of small masses of water has been variously referred to as an alternating convective circulation, mixing phenomenon, eddy or vortex motion, and turbulence. Jacobsen's and other recent investigations in this field indicate that this phenomenon is the cause of the processes of diffusion, heat conductivity, and frictional resistance peculiar to oceanic conditions. Comparable values of the "Mischungsintensitat," a coefficient indicating the intensity of the rate of interchange of small water masses, have been deduced independently from the distribution of temperature and salinity, and also from the dynamical treatment of current observations. Thus studies of temperature and salinity distributions may yield appropriate values of the frictional resistance, an essential factor in the dynamical solution of ocean-current problems as well as certain tidal problems. This frictional resistance about which there is so little definite information appears to vary widely with the locality, wind velocity and other factors. It is not a "physical constant" of the *substance,* water.

The precise nature of this mixing motion can not be directly determined, but various reasonable assumptions regarding it can be made, and combined with known fundamental facts into a quantitative theory or generalization, from which deductions can be made, and tested by comparison with observations. Encouraging results already reached appear to justify

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[1] Ekman, V. W. 1905–06. On the influence of the earth's rotation on ocean currents. Arkiv for Matematik, Astronomi och Fysik, 2, 1-53, 1 pl. and 10 figs.

[2] Nansen, Fridtjof. 1902. The Norwegian North Polar Expedition, 1893–1896. Scientific Results, Vol. III, Longmans Green & Co. London, part IX, pages 1–427. 33 pls.

[3] Bjerknes, V. F. K. 1901. Circulation relative zu der Erde. Öfversikt af Kongl. Vet.-Akad. Förhandl., 58, 739–757.

[4] Krümmel, O. 1911. Handbuch der Ozeanogriphie (Stuttgart, Engelhorn), 2, xvi, 766 pp., 182 figs. in text.

[5] Jacobsen, J. P. 1913. Beitrag zur Hydrographie der Dänischen Gewässer. Medd. Komm. Havandersogelser (Hydrografi), 1, no. 94, pp., 14 pls., 17 figs. in text.

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further efforts in this direction and point to the possibility of a satisfactory coordination of the various phenomena of conduction, diffusion, and fluid friction by means of a single mathematical theory of the mixing motion. Such an investigation, if successful, would enable one to deduce the temperature distribution in a body of water gaining heat from solar radiation of given intensity, and losing heat by evaporation. Investigations of this simplest case would thus correlate under definite physical principles all of these various thermal phenomena. Again, by so amending such results as to include the effect of a given flow or current on the distribution of temperature determined for the above simplest case, estimates of a current could be made from the difference between the undisturbed and the actual temperature distribution. This has been partly worked out and applied to the determination of the velocity of upwelling in the San Diego region. Thus the temperature disturbance can be quantitatively treated as an effect of a current, without regard to its dynamical causes. Qualitative conclusions relative to ocean currents have long ago been reached from essentially the same general idea, and this fact points to the possibility of such a quantitative theory. Such general quantitative laws of the relation between currents and temperature departures from the undisturbed state might be combined with Bjerknes's dynamical theory, and thus afford a means of deducing answers to more involved questions, such as the following: Given the distribution of solar radiation over the surface of a body of water having given boundaries, and a known initial temperature distribution, to determine the resulting temperature distribution and circulation for any later time. The results of similar determining conditions have not infrequently been either assumed or surmised in order to form a basis for more far-reaching oceanographic conclusions. But it is by the *precise* formulation and sufficiently *accurate* solution of suitable specific problems sufficiently in accord with actual conditions that general laws of oceanic phenomena can be discovered and tested. And the greater the variety of such ideal problems that we are in position to attack, the greater will be our progress in the precise and detailed study of the physics of the ocean. Also, it is to be expected that a satisfactory physical theory, especially of the mixing phenomenon, would greatly aid in the solution of certain problems of sedimentation and ocean chemistry.

One problem of ocean physics, whose simplest special case would be to deduce the vertical temperature distribution in a body of water exposed to solar radiation of approximately uniform intensity over the surface and losing heat by evaporation and conduction from its surface, has received very little attention except of a qualitative or speculative nature. Yet this problem appears to be fundamental in precise oceanographic investigations. Accordingly, the author has for some time attempted to work out a solution, and after trying and rejecting various assumptions, has reached encouraging preliminary results by using certain concepts from statistical mechanics, combined with elementary laws of heat and radiation. It is hoped that these studies will have progressed far enough for publication within a year or two. It is also the intention, after this

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work on temperatures is in a more finished state, to investigate the problem of diffusion in the sea by similar methods applied first to certain of the numerous salinity determinations made by the Scripps Institution. Problems of the type mentioned in this paper form an extensive and promising field of fundamental importance in oceanography, and demand the attention of all investigators interested in promoting quantitative studies of the sea, but probably only a few will desire to engage actively in their solution.

It has formerly been necessary to make a great deal of use of such scattered data as the investigator could find as a basis for theoretical work. Much has been, and doubtless will be, accomplished in that way. And all original detailed data, as well as summaries and deductions therefrom, should be accessible in some way to investigators, even if publication is not always practicable. But such a procedure has obvious disadvantages, such as insufficient or unknown precision, incomplete data, or lack of significant factors that may impair or greatly restrict the conclusions. Therefore it is also necessary to conduct special programs of observations, designed with reference to particular problems, in order to improve and supplement the above more extensive and preliminary type of work. Thus selection of the locality, season, etc., and the observation of all relevant phenomena affords as nearly as possible a realization of the advantages of the physicist who controls the conditions affecting his laboratory experiments. For example, serial temperatures observed in the central part of a high-pressure area away from currents or land, and where prevailing great depths provide results corresponding to the simplest conditions, would be of great aid in the study of "normal" temperature gradients. Such observations should also be accompanied by observations on the intensity of solar radiation, turbidity, salinity, and evaporation, and should be continued through different seasons and times of day in order to provide the most important kinds of data. Very little of this intensive type of work, carried on with sufficient continuity and completeness, has been done, and it has been restricted to certain portions of small inland seas or inshore regions. Although results thus obtained are valuable in themselves and as a means of interpreting such fragmentary and widespread data as may be available, they can not take the place of similar intensive work at selected stations throughout the ocean. Actual conditions in typical areas of the great ocean must be carefully observed and studied, if any reasonable approach to exhaustive oceanographic investigations is to be realized.

In this paper I have dwelt especially on the deductive treatment of ocean problems, because of the great need of improvement in this aspect of the subject. Although admitting that purely empirical or statistical methods are indispensable in assembling and coordinating various kinds of field data, it seemed desirable to urge the need of progress from such empirical results toward the goal of a complete deductive treatment carried out in accordance with known generalizations of physics.

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STATE OF PROGRESS IN CONTINUOUS RECORDING OCEANOGRAPHICAL INSTRUMENTS

By Albert L. Thuras

The modern tendency in physical research is to replace indicating instruments by recording instruments wherever possible. This has been especially true in the science of meteorology where the recent advances have been brought about almost entirely by the remarkable improvements and developments in recording instruments. In the related science of physical oceanography there are practically no recording instruments now in general use, except possibly the tide-gage. If meteorology has been so greatly benefited by such instruments, surely in oceanography, where the changes in the physical properties are so much more regular and therefore more easily interpreted, great advances should be looked for through the addition or substitution of recording instruments.

Heretofore the methods of collecting physical data have been such that no complete knowledge of the physical characteristics of the particular body of water under investigation have been obtainable as the work is progressing. The procedure has been to lay out stations, as intelligently as possible along courses throughout the region of the ocean to be studied which will give the most important information. At these various stations with the use of water bottles and reversing thermometers samples and temperatures of the ocean water are obtained at various depths down as far as the investigations are carried. The thermometers are read as soon as the water bottles are drawn up and samples of the water are stored in bottles which are later chemically measured for salt content in a laboratory on shore. The several disadvantages of this method are apparent: (1) No working knowledge of the ocean water is immediately obtainable and consequently no rearrangement or addition of stations can be made from an examination of the data taken. This is very important especially where our knowledge of the ocean is limited and one wishes to explore the magnitude and extent of the surface and submarine currents. (2) It is impossible to obtain a corroboration of any data where there may be doubt as to the accuracy or reliability of single observations. (3) The data taken are usually inadequate and especially so at those stations where vertical lines of observations pass through various strata of water of different salinity, temperature and density. Curves and cross sections plotted from data taken in these regions are usually a matter of approximation and give very little information as to the mechanism of the mixing of waters of widely different properties. These observations are particularly inadequate in such regions as the southern end of the Grand Banks of Newfoundland where the cold waters of the Labrador Current merge into the warm saline waters of the Gulf Stream.

With the object of improving the technique of the science of physical oceanography, an effort has been made in recent years to develop practical

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recording instruments which are sufficiently rugged and simple to be used on shipboard. The most important physical properties of the sea of which a continuous record should be made, are temperature, salinity, density, velocity and direction. The first three properties are so related that any one can easily be deduced from a measurement of the other two. The properties most easily measured are temperature and salinity. Salinity is defined as the number of grams of salts in a liter of sea water. From a consideration of the properties of sea water that vary with the salinity, the electrical conductivity seems to be the most susceptible to continuous measurement if the difficulty due to the variation of conductivity with temperature can be overcome. Such a method consists in measuring the ratio of the resistance of sea water in two equal or nearly equal electrolytic cells, one cell containing sea water of a known salinity and the other having the sea water to be measured flowing through it. The ratio is obtained by a Wheatstone bridge, using alternating current to eliminate polarization effects in the cells. A record of the resistance ratios of the two cells is made by an automatic electrical recorder. By immersing the two cells in the same temperature bath almost complete compensation of temperature changes is effected.

A continuous record of the temperature of the ocean is most easily obtained with a platinum resistance thermometer and an automatic regulating Wheatstone bridge quite similar to the continuous salinity recorder. This instrument has been used successfully on shipboard for several years in the region of the Grand Banks of Newfoundland and some very interesting records have been obtained which show the distribution of temperature and thereby indicate the location of ocean currents and also give a knowledge of their boundary conditions which could hardly be obtained by repeated single measurements of temperature.

The continuous recording instruments for temperature and salinity described above give only surface measurements but they could easily be constructed for making measurements below the surface. This would require the use of an insulated cable of 4 or 5 conductors which would be sufficiently strong and flexible. During 1918–19 in connection with submarine listening experiments there were constructed reinforced cables similar to these, which could be repeatedly wound on to and off of a drum and would withstand a weight of 400 to 500 pounds. Data from these instruments gave accurate curves of temperature, salinity and density from the surface down to a depth of probably 500 meters, which is the most interesting part of the ocean dynamically.

R. A. Daly of Harvard University has developed and built a thermograph which can be anchored in very deep water and will give a record of temperature for a period of several days. The instrument has an intermittent mechanism which gives periodic photographs of a mercury column. This instrument was specially designed to withstand very high pressures and it should be especially valuable in studying the small variations of temperature at great depths in the ocean.

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The measurement of the movement of waters in the ocean has been quite difficult to perform experimentally. This difficulty has been due chiefly to the non-continuity of measurements and the unknown movements of the vessel from which the measurements are made. Dr. Hans Pettersson of Goteborg, Sweden, has solved this problem by his photographic current meter which will give a continuous record of both direction and velocity for a period of two weeks. This instrument with the use of special anchors and buoys, can be firmly secured at any depth down to 300 meters. The difficult problem which had to be solved in this instrument was the transfer of the motions of a propeller through a water tight case containing the recording apparatus without the addition of friction. This was accomplished by a magnetic coupling.

Dr. Pettersson has also developed densimeters to be used from shore stations which give a record of the movements of the waters of various salinities into and out of the Swedish Fjords. These instruments consist of vessels or cans whose density is equal to the average density of the Fjord waters. As the submarine waves of high salinity come in from the ocean these vessels will rise and a record of their height is automatically recorded. Some interesting theories of submarine waves have resulted from this work and the correlation between the variations of salinity and the abundance of fish in these Fjords is being studied.

This briefly describes the recent developments in recording instruments and in conclusion I wish to suggest the possible application of these instruments to future research in physical oceanography.

A comparison of the yearly observations in the region of the Grand Banks of Newfoundland shows that the volume and strength of the Labrador Current have a decided influence on the course of the Gulf Stream in that vicinity. In some years the Gulf Stream was found almost up to the southern end of the Grand Banks and in other years as far south as the 40th degree of north latitude, a variation of over 100 miles. An accurate knowledge of the volume, velocity and location of these currents from time to time and correlation with meteorological conditions might yield results of great interest.

This information could be obtained by the use of recording instruments in the straits of Florida and across the Gulf Stream before it branches out east of the Grand Banks of Newfoundland.

With continuous salinity and temperature recorders placed on trans-Atlantic vessels a complete record of the variation of temperature salinity and density could be secured across the Atlantic from month to month. These instruments would make measurements at a constant depth below the surface and might throw considerable light on the hydrodynamics of this part of the Atlantic.

It seems to me that the science of physical oceanography has passed the period of exploration and has now reached that stage in its development which calls for a program of research on a large scale with most carefully thought out plans of systematic investigation extended over long periods

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of time. Results from such an undertaking I believe can be most successfully accomplished by the use of recording instruments.

Western Electric Company,
New York City.

PRESENT STATUS OF RESEARCHES ON MARINE SEDIMENTS IN THE UNITED STATES

By Thomas Wayland Vaughan[1]

INTRODUCTION

The ocean of today stands at the end of a succession of oceans that have existed since land and water were first divided from each other on the earth's surface. This fact, admitted by everyone, needs to be emphasized in order to make clear the transcendent importance of the study of marine sediments. It is possible to measure the depth and the temperature of the waters of the present ocean, to sample its waters from the surface to the bottom of its greatest abysses and examine them chemically, and to measure directly or to infer from measurable factors its currents. It is also possible to study the sediments deposited on the floor of the ocean and around its margins. These and other features of the present ocean can be known by direct processes but over a large part of the earth's surface where there was once sea there is now only land, and the depth, temperature, chemical composition, and currents of bodies of waters no longer existent cannot be measured. That seas once extended over regions now land is known through the record made by the sediments and these sediments supply the fundamental data for recognizing the physical features of the vanished oceans.

Considerable information has already been acquired on modern marine deposits and preliminary maps of parts of the ocean floor have been made. Among the sources of this information are the studies of Bailey and Pourtalès, the classic work of Murray and Renard, Murray, and Murray and Lee, Murray and Philippi, and Philippi, the many papers by Thoulet, several papers by Böggild, including his recently published "Meeresgrundproben der Siboga-Expedition," papers by Walther, and the studies of the shoal-water deposits of Florida and the Bahamas and Murray Island, Australia, with which I have been associated.[2] Of course there are many other authors but I have given the names of those who have done most in areally mapping deposits on the bottom of the sea. The great leaders are Murray and his associates, among whom Philippi is to be reckoned, and Thoulet. It is believed that the characteristics of some deposits and the relations of these deposits to the conditions under which they formed have

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] K. Andrée is the author of a useful bibliography on literature on marine sediments published between 1841 and 1911. See his article, Uber Sedimentbildung am Meeresboden, Literaturzeichniss: Geolog. Rundschau, 3, 1912, 324-338.

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been ascertained with enough accuracy to admit their use in interpreting geological history; but how inadequately some relations are understood is exemplified by the presence of red clay at comparatively shallow depths, 4000 meters, in the enclosed deep basins of the East Indian Archipelago. Böggild says it is necessary to conclude that the capacity of the water to dissolve calcium carbonate is greater in the enclosed basins of the East Indian Archipelago than in the open ocean.[1] Although considerable is known about marine sediments, the information is far below what is needed to understand many important features of sediments in the modern oceans and to supply a basis for interpreting ancient sediments.

RESEARCHES ON MARINE SEDIMENTS IN AMERICA

There is under the Division of Geology and Geography of the National Research Council of the United States a Committee on Sedimentation composed of fourteen members, of which I have the honor to be chairman. This committee is divided into seven subcommittees, as follows: universities and colleges east of the Allegheny Front; universities and colleges between the Allegheny Front and the Rocky Mountains; universities and colleges west of the Rocky Mountains; state geological surveys; chemical and physical researches on sediments; field description of sediments; preparation of a treatise on sedimentation. The report of the committee for the year ending on April 28 has been transmitted to the chairman of the Division of Geology and Geography and is available in mimeographed form to interested persons.

No attempt will be made to give an account of the work of the committee, as that would consume too much time, but it will be said that its scope includes both modern and ancient sediments and both continental and marine deposits. One of the purposes of the committee is to ascertain and to follow all current investigations on sediments within the United States and the machinery for accomplishing this purpose is good.

The U. S. Bureau of Fisheries is trying to arrange for a study of the sediments of the Bay of Maine but the plans have not yet been completed; and an attempt is being made to have the sediments of Chesapeake Bay studied cooperatively by the Bureau of Fisheries, the U. S. Geological Survey, and Johns Hopkins University, but the actual work on the bottom samples has not begun. Prof. G. D. Louderback has been trying to study the bottom deposits collected principally by the Bureau of Fisheries in San Francisco Bay. Some preliminary information on the samples has been published but the investigation has progressed slowly. Two researches with which I have been concerned have had grave difficulties. One of them, the study of the sediments off the mouth of Mississippi River, as representing an area in which great quantities of terrigenous material are being deposited, has come to a standstill with the resignation of Mr. E. W. Shaw from the U. S. Geological Survey. The other study

[1] Böggild, O. B., Meeresgrundproben der Siboga Expedition: Siboga Expeditie. Mon. 45, p. 11, 1916.

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is on the shoal-water deposits of southern Florida and the Bahamas, as representing areas in which very little or no terrigenous material is being deposited, except at the north end of the Florida reef. Fortunately several papers on the Floridian and Bahamian samples themselves and on correlated phenomena, such as papers by Dole and Chambers and Wells on the chemistry of the waters, bacteriological studies by Drew and Kellerman, and temperature records by me, have been published, but a large quantity of data remains unpublished. I am hopeful that within a relatively few months all data already acquired, which include Ekman current meter measurements at about 15 stations, may be prepared for printing.

The researches of F. W. Clarke and W. C. Wheeler on the inorganic constituents of the skeletons of marine organisms is of prime importance but such work needs to be correlated with studies on the bottom deposits themselves. The research on which Clarke is now engaged, the composition of river water discharged into the sea, is also of great value. Wells's researches, such as his published "New determinations of carbon dioxide in water of the Gulf of Mexico" and the studies he is now making on the waters of Chesapeake Bay, are also of much value in understanding problems of sedimentation, but the sediments themselves need to be studied. Richard Field of Brown University is studying some features of modern shoal-water limestones, and E. M. Kindle of the Canadian Geological Survey is conducting important researches on modern limestones; but Kindle may not be credited to the United States.

Of the researches above enumerated, five deal with bottom samples and areal surveys of the sea bottom. The areas are the Bay of Maine, Chesapeake Bay, southern Florida and the Bahamas, the mouth of Mississippi River, and San Francisco Bay. No one of these researches is progressing in a satisfactory way. Furthermore, all these researches deal primarily with shoal-water deposits—there is no work on deep-sea deposits. The only modern deep-sea samples recently described from America are two I described in 1917 from the Tongue of the Ocean, Bahamas. This, it seems to me, is a very poor showing for the United States.

FACTORS THAT RETARD RESEARCHES ON SEDIMENTS

During the period that the United States were participants in the World War, investigations on sediments suffered as did many other kinds of scientific work and our country has not yet finished its readjustment after the conflict. Besides the interruption caused by the war, several competent investigators have been diverted by other duties and a new crop of investigators has not yet ripened.

The interruption of investigations and the diversion of investigators are not the only difficulties in the way of studies of sediments. The subject is one that does not belong exclusively in any one of the sciences as the sciences are currently classified, although those engaged in several kinds of scientific endeavor recognize the value of knowledge of certain aspects of it in the proper performance of some of their work. The engineer,

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for instance, wishes to understand shore-drift in certain places and the rate of the deposition of sediment in harbors; the student of fisheries wishes to know the relations between bottom material and organisms that may be used as food; the navigator may keep his course through fog and snow by detailed knowledge of the bottom; and the geologist may utilize knowledge of sediments in interpreting some geological formation of economic significance. Of the different kinds of scientific men the geologist is the most broadly concerned, because only by an adequate knowledge of the modern can he understand the ancient deposits and it is part of his work to study the mechanical features and the constituents of sediments, both modern and ancient, though he usually feels that his attention should be directed to past rather than to present history. This is a practical day and students inquire how they can make work on sediments pay. It has been possible to provide funds for some work on sediments but the remuneration is far below that offered by oil companies.

MEANS FOR PROSECUTING RESEARCHES ON SEDIMENTS

In remarks already made I have tried to bring to your attention the present status of researches on marine sediments in this country and I have indicated some factors that I believe retard such investigations. How can the backward condition of researches in this important subject be remedied? I will venture a few suggestions.

My first suggestion is that those interested endeavor to impress upon students the scientific importance of investigations on sediments. This may best be done by the establishment of courses in sedimentation in our universities and the offering of fellowships to graduate students for investigations in the subject. At present courses in sedimentation are given at the universities of Wisconsin, Iowa, and California, and at the University of Iowa a research fellowship is maintained. Courses should be given at more universities and there should be more research fellowships. The Geophysical Union might combine with the divisions of Geology and Geography and of Biology and Agriculture and endeavor to establish two or three more fellowships in sedimentation.

In addition to university work of the kind indicated an institution or institutions in which complicated special studies may be undertaken are needed. An institution comparable to the Geophysical Laboratory of the Carnegie Institution would fulfil the great need but an endowment that will yield an income between $50,000 and $75,000 per year is not easily obtained. However, it is worth striving for. As such an institution does not exist it may be preferable to try to utilize existing institutions by appealing to them and trying to strengthen them. The study of sediments is a fundamental of geology and the U. S. Geological Survey has recognized this and has tried to develop researches on sediments as a part of its work. Furthermore, many geologists, because of their training, are prepared to undertake such investigations. It is, therefore, suggested that those interested in such work make their desires known to the director of

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the U. S. Geological Survey, that it be pointed out to him how the Geological Survey by doing such work can help science and serve other governmental bureaus, and that he be requested to do as much as the circumstances of the Survey will permit. The Geological Survey has already done enough to place students of sediments under deep obligations to it. If it could study and prepare reports on bottom specimens one of the present difficulties in the way of advance in knowledge of marine bottom deposits would be removed.

Until now it has been possible to obtain larger collections of properly taken bottom samples than it has been possible to study. The U. S. Bureau of Fisheries is fully equipped to collect samples precisely as they should be taken and the heads of that Bureau are anxious to do all they can to aid researches on sediments. Perhaps if provisions could be made to study the samples, the U. S. Coast and Geodetic Survey might make systematic collections. Other than governmental agencies, especially the Department of Marine Biology of the Carnegie Institution, have shown willingness to help in procuring bottom samples for study. The material available for investigation is large in quantity and much of it has been properly collected and is accompanied by all needed data. If these collections could be properly studied and reports on them published, what fine contributions would be made to our knowledge of marine sediments!

CONCLUSION

In conclusion I wish to emphasize the value to science of a proper understanding of the marine sediments in the ocean of today. A proper understanding of these sediments includes knowledge of the depth, temperature, and salinity of the waters above them, the distance from shore to where they were deposited, their relations to currents, and if near land, the relief of the land, its climate, and the rocks composing it. Through such knowledge of modern sediments the criteria for interpreting the sediments of ancient seas are discovered. Having established the needed criteria, the boundaries of the old seas may be traced; the physiography, constitution, and climate of the neighboring lands may be recognized, and the depth, temperature, chemical composition, and currents of the waters of the ancient oceans and the organisms that inhabited them may become known. Modern sediments, though important in understanding what is today, are doubly important because knowledge of them supplies the only key to what would otherwise be an unknown past.

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THE INTERVALS THAT SHOULD OBTAIN BETWEEN DEEP-SEA SOUNDINGS TO DISCLOSE THE OROGRAPHY OF THE OCEAN BASINS

By G. W. Littlehales

The intervals between sounding stations must be gauged by the dimensions of the orographical features whose presence it is intended to disclose. Leaving out of consideration details of topography and confining the attention to features of the greatest prominence, inquiry must be made as to the form and dimensions of the slenderest isolated submarine peak that could be raised from the floor of the ocean to a mountainous height and remain standing under the stresses of its own weight and of the superincumbent body of water. For if the spacing of soundings be such as to give indication of the presence of the slenderest form that could stand, then evidence of the presence of any orographical forms that may exist is likely to be afforded. Theoretically, the shape of an isolated submarine peak would be that of a solid of revolution in which the resistance to crushing of any horizontal section is equal to the combined weight of the portion of the formation above that section and of the superincumbent body of water.

Let y denote the radius of any horizontal section and z its distance from the top of the formation. Let K denote the coefficient of resistance to crushing of the material composing the formation; w, the weight of a unit of its volume; and w′, the weight of a unit volume of sea water.

Accordingly, $\pi w \int y^2 dz =$ the weight of the formation above any section whose distance from the top is z, $2\pi w' \int y.z.dy - \pi w' \int y^2 dz =$ the weight of the water upon the formation above any section whose distance from the top is z, assuming the top of the formation to reach to the surface, $\pi K y^2 =$ the strength of any section to resist crushing, and

$$\pi w \int y^2 dz + 2\pi w' \int y.z.dy - \pi w' \int y^2 dz = \pi K y^2 \qquad (1)$$

By differentiation, equation (1) becomes

$$\pi w y^2 dz + 2\pi w' y.z.dy - \pi w' y^2.dz = 2\pi K.y.dy \qquad (2)$$

which expresses the condition that the increase of strength of any section in excess of that of the section next above is equal to the sum of the increases of the weight of the formation and the weight of the water upon any section in excess of their combined weight imposed upon the section next above.

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Letting S denote the area of any horizontal section whose radius is y, and dS, the differential of S, equation (2) may be written in the following forms:

$$w.S.dz + w'.z.dS - w'S.dz = K.dS$$

$$(w - w')\,S.dz = (K - w'z)\,dS$$

$$\frac{dS}{S} = (w - w')\frac{dz}{K - w'z} = \frac{w - w'}{w'} \cdot \frac{dz}{\frac{K}{w'} - z}$$

By integration, equation (3) becomes

$$\log S = -\frac{w - w'}{w'} \log\left(\frac{K}{w'} - z\right) + C$$

in which C is the constant of integration.

$$\text{Hence } \log\left(\frac{K}{w'} - z\right) = \frac{w'}{w - w'}\,C - \frac{w'}{w - w'}\log S$$

$$\text{or } \frac{K}{w'} - z = \frac{E^{\frac{w'}{w - w'}C}}{E\left(\frac{w'}{w - w'}\log_e S\right)}$$

In the absence of knowledge of the value that should be assigned to K, the coefficient of resistance to crushing, this equation has been used in the generalized form,

$$A - z = \frac{B}{E\left(\frac{w'}{w - w'}\log_e S\right)} = \frac{B}{E\left(\frac{1.03}{2.67 - 1.03}\log_e S\right)} = \frac{B}{E^{1.46 \log_{10} S}},$$

to find the equation of their average form from the observed bathymetrical data on Seine Bank in latitude 33° 50′ N. and longitude 14° 20′ W., Cocos or Keeling Island in latitude 12° 06′ S. and longitude 96° 53′ E., Enderbury Island in latitude 3° 10′ S. and longitude 171° 10′ W., Funafuti Atoll in latitude 8° 25′ S. and longitude 179° 07′ E., Taviuni Bank in latitude 12° 05′ S. and longitude 174° 35′ W., and the shoal near Midway Island in the North Pacific Ocean in latitude 28° 00′ N. and longitude 177° 40′ W.

For this purpose the values of z and y, expressed in nautical miles, were inserted in the above equation, and a conditional equation was formed for each pair of coordinates relating to each of the submarine formations. From these conditional equations normal equations were

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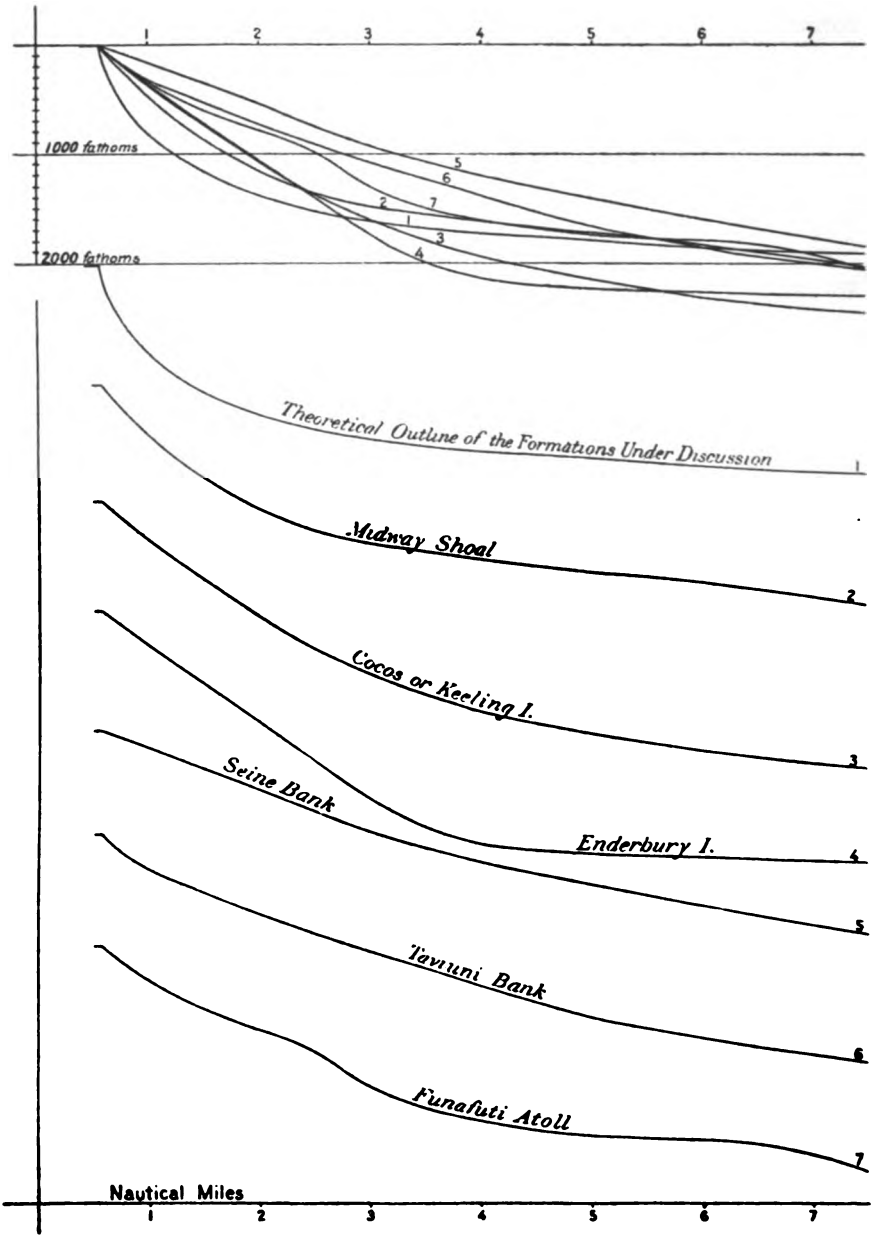

FIG. 1. Profiles of isolated submarine peaks.

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found by the method of least squares, which gave the values of the constants A and B. The resulting equation is $1.87 - z = \frac{1.87}{E(1.446 \log_{10} \pi y^2)}$ and the corresponding curve, which by revolution around the vertical axis would generate the average form, is shown in figure 1, together with others which have been plotted for purposes of comparison from measured data. This investigation shows that isolated formations occupying comparatively limited areas at the bottom can and do occur in the ocean depths, and we are able to assign at once the maximum interval that should obtain between deep-sea soundings taken in operations directed toward the development of the orography of the bottom of the sea. An interval of 8 miles coupled with a differential interval of 2 miles would serve for general development, and would prove with certainty the existence or absence of any formation rising close to the surface. Of all the possible ways in which an 8-mile interval could lie with reference to a submerged peak, that which would be most advantageous for a prompt discovery of its existence is the condition in which one end of the interval is at the bottom of the slope and the other near the apex, and that which would be least advantageous is the condition in which the interval is bisected by the position of the apex. In the latter case, there would be nearly equal soundings at both ends, but the soundings at the ends of the adjacent two-mile intervals would in all probability give indication of the slopes.[1]

---

[1] Following the presentation of this paper the following suggestion was made by Harry Fielding Reid:

Dr. Littlehales' remarks about the soundings in the oceans bring up a matter that I have had in mind for some time; that is, the value of a detailed sounding of a single deep. We know very little indeed about the shape or conformation of the great ocean deeps; a detailed set of soundings of a particular deep, to bring out not merely the general slope of the bottom, but also details of configuration, would be of great value. If, as seems probable, the great deeps are due to faulting, the soundings should be close enough together to show the existence of fault-scarps. A deep which offers especial facilities for such determinations is the Virgin Islands or Bronson Deep. It is a long east and west trough, lying a little north of Porto Rico, with a recorded sounding of 4,662 fathoms (the greatest depth measured in the Atlantic); although but few soundings have been made in its deeper parts. Its situation is very convenient; San Juan could be used for a base for the western part and St. Thomas for the eastern part.

There are, of course, other parts of the Caribbean region where soundings would be valuable, but I think a detailed sounding of a single deep would yield more valuable results than scattered soundings over a larger area.

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NEW METHODS OF OBSERVING WINDS AT FLYING LEVELS OVER THE OCEAN

By Alexander McAdie

Aerography may be defined in a general way as a study of the structure of the atmosphere. There are various ways of obtaining information regarding the flow of air at different levels and the conditions of density, pressure, and temperature of the mixture of air and vapor. Exploration of the upper air has been accomplished by means of close study of the clouds; the establishment of mountain observatories; the ascent of manned balloons; kites and kite balloons; sounding balloons and pilot balloons. To these we propose to add another where measurement is made from the deck of a vessel by employing certain predetermined lapse rates, or rates of fall in temperature with elevation.

The principle in brief is that provided sufficient water vapor is present and condensed as cloud, the height of the level of condensation is a function of the lapse rate. The height can be obtained then from observations of the actual temperature, the temperature of evaporation and the temperature of saturation at sea-level, making proper corrections for surface speed and direction.

It is a little more than twenty years since Teisserenc de Bort at Trappes, and Lawrence Rotch at Blue Hill, close friends and co-laborers, began the systematic sounding of the atmosphere by means of sounding balloons. With the war came a widespread use of pilot balloons. Today, *sondages* are made (or are supposed to be made) at all United States naval air stations, and at many land stations. During the war information regarding the speed and direction of the winds at flying levels thus obtained was of great value—not alone to the airmen, but also to artillerists and gas men.

There is no special difficulty in using sounding balloons or pilot balloons on land; but at sea the sounding balloon is out of the question, owing to difficulty of recovering the record. Pilot balloons, however, can be used; and during the trans-Atlantic flight of the N. C. boats, I obtained fully a hundred observations from sea-level up to 4 or 5 kilometers, while stationed on the U. S. S. *Baltimore* (mine layer).

We can not, however, expect navigating officers of our merchant marine to send up balloons, follow them with theodolites, record the elevations and angles, plot the trajectories and deduce from these the speed in meters per second and the direction of motion for the different levels. Not but that it would pay to do so; for it *will* pay any navigating officer to be posted concerning the structure of the air. It may sometimes mean the safety of the ship. And an intelligent aerographic officer with a moderate outfit of aerographic apparatus on a ship like the *Mauretania* could tell from the upper air movements studied in connection with the surface circulation, the location of the ship with reference to the true

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centers of gyratory and translatory flow, and could forecast the future path of the storm. A daily weather map or one at more frequent intervals, based on reports received by radio, could be made and used to great advantage with this added knowledge of the upper air conditions.

In cloudy weather the pilot balloon may soon be lost and it is therefore advisable to substitute for the balloon method a method which makes use of clouds, especially lower clouds within 35 degrees of the zenith. Of course in dense fogs, neither method can be used.

The new method makes use of a specially stabilized nephoscope with automatic sighting rods, and an arc with tangent values; also a new type of hygroscope. The combination may be called a marine altoscope.

The nephoscope consists of a black mirror suitably mounted (for details of construction see *Blue Hill Report,* 1910) to permit of motion in azimuth, proper leveling devices, and graduated circle, reading clockwise and in either degrees and tenths or in grads. To this mirror is attached a stabilizing device, suggested by Professor R. W. Wilson of Harvard University. The mirror thus keeps a horizontal position regardless of the ship's motion.

A metal arc or quadrant springs from the plane of the mirror and is graduated in degrees, and also in natural tangents, the reason for which will appear later.

At the free end of the arc a vertical rod is mounted and carries a pantagraph or diamond-shaped rectangle supporting two rods for sighting the cloud. Use is made of the reflection of the line joining cloud and eye, and the second sighting rod forms a straight line prolongation of the line from the center of the mirror to the cloud. The value of this is in fixing the eye, whatever the ship's motion may be. When once set, the eye can be withdrawn or rested for a few seconds and then brought back to the original position without delay or uncertainty. The radials can be provided with sleeves permitting extension.

In observing, first level the instrument. Bring the zero which is also 360° or 400 grads of the horizontal or azimuth circle to the true south point. The circle is graduated clockwise and the true west will therefore be 100 if scale is in grads (90° if in ordinary units).

Since the reflection of the cloud crosses the mirror in the same direction as the cloud is moving, the reading on the azimuthal circle where the cloud image passes off the black mirror will be the direction or angle ***from which the wind is blowing.***

The quadrant is now swung into position, making the same angle. With the control screw provided for the purpose of raising or lowering the sighting rods, bring the nearer sighting rod into perfect alignment with the reflection of the other sighting rod. This latter rod joins the cloud point and the center of the mirror. We have now the angular elevation of the cloud from a true horizon. When this angle is 50 grads or 45 degrees, it is plain that the distance the reflection of the cloud moves in the mirror is equal to the height of the intercept corresponding to the

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height of the cloud; that is, the sine and cosine of the angle are equal, and the natural tangent is unity.

In such a case, we have only to divide the height of the cloud (to be determined later) by the number of seconds to get the rate in meters per second.

If, however, the cloud line does not make an angle of 45, we use directly the value of the tangents. The following condensed table gives these values:

Tangent	*Grads*	*Degree*	*Tangent*	*Grads*	*Degree*
.4 =	24	22	1.6 =	64	58
.5 =	29	26	1.7 =	66	59
.6 =	34	31	1.8 =	68	61
.7 =	39	35	1.9 =	69	62
.8 =	43	39	2.0 =	70	63
.9 =	47	42	2.5 =	75	68
1.0 =	50	45	3.0 =	80	72
1.1 =	53	48	4.0 =	85	76
1.2 =	55	50	5.0 =	87	79
1.3 =	58	52	6.3 =	90	81
1.4 =	60	54	11.4 =	95	85
1.5 =	62	56	∞	100	90

One has only to divide the height of the cloud by the arc reading (i. e., tangent value) to get the horizontal distance. This last divided by the number of seconds gives the speed of the cloud in meters per second. We thus have direction and speed of the air at the cloud level, provided the height of the cloud is known.

To get the height we use a special type of psychrometer (McAdie cryoscope). The improvements over the usual psychrometers are:

(1) The amount of air passing over the wet-bulb is under control; i. e., a definite value is given to the wind factor in evaporating the film of water.

(2) The method of wetting the bulb is novel. The old method of using a wick or muslin cloth, bringing a constant supply of water by capillary action, is replaced by a fine metallic mesh shaped to slide over the bulb, easily wetted and containing a known small weight of water, to be evaporated in a given time.

(3) The conversion of vapor pressure into units of force permits the use of a simple equation connecting the actual temperature, evaporation temperature, and saturation temperature.

Of the above factors, the wind velocity is of great importance and must be known definitely if the humidity records are to be regarded as reliable. It may be pointed out that even in official meteorological services at home and abroad the records of relative humidity are open to criticism on the ground of uncertain ventilation. In the best forms of sling and whirling devices no record is kept of the time and number of revolutions.

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In the present instrument a definite wind velocity is automatically maintained and the beginning and ending of the movement of the air over the evaporating surface, or what is approximately the same, the movement of the wet-bulb through the air, is definite. The wetted bulb can be swung either vertically or horizontally at any desired speed from 4 to 10 meters per second. The thermometers are carried by a frame which slides on the rod and their distance from the top of the rod or axis of rotation determines the velocity of the equivalent wind. Thus at a distance of 100 centimeters (39.3 in.) the bulb when whirled will travel in one complete revolution 6.283 meters (approximately 20 ft.). It is then only necessary to know the number of rotations and the time to get the speed of the wind. An automatic counter is so connected with the handle that at the completion of every hundred revolutions an alarm bell rings. With a little practice one makes 100 swings per minute.

If desired a watch may be used and the number of seconds counted. The rate mentioned, one hundred per minute, is equivalent to a wind of 10.5 meters per second (23.5 miles per hour).[1]

Now, the rate of evaporation varies as the square root of the wind velocity. Thus the rate at 10.5 m/s is to the rate at 4 m/s as 16 to 10. The hygrometric tables in common use were based on experiments in which the speed of rotation was approximately 4.5 meters per second, although no definite statements are made and there appears to have been no special attention paid to the speed of rotation or the rate of fanning of the wet bulb. Naturally discordant results are obtained by different observers. The speed mentioned (4.5 m/s) is somewhat too low for a good circulation of air, and is indeed below the average wind value at most places. The value of 10 meters seems to be a more representative figure.

In the present instrument the pressure of the water vapor at any temperature ordinarily met with above the freezing point is expressed in units of force, and so far as known this is the first instrument employing these units for water vapor. A kilobar is that pressure which if exerted as force would give an acceleration of one centimeter per second per second to a mass of weight one kilogram. Roughly, it is the pressure given by a wind of 12 meters per second on a plane one meter square and at right angles to the wind. Thus, temperature, pressure and weight are expressed in a uniform, consistent and scientific set of units, namely, the

[1] In the sling psychrometer used by the Bureau of Mines, if we assume a speed of 100 revolutions per minute the equivalent wind would be about 2.9 m/s (6 miles per hour). There is no counting device and while a higher rate can be obtained, it is difficult to count by the eye more than 120 per minute. In the whirled psychrometer used by the Weather Bureau, the radius of rotation of the bulbs is about the same as in the Bureau of Mines instrument, but a geared handle permits of varying the rate from 175 to 260. The velocity equivalents will vary from 9 to 16 miles per hour, the rate of evaporation in the former being only 75% of that in the latter. McAdie has suggested a simple form of counter for this instrument to standardize the results and has used such a device at Blue Hill Observatory for two years.

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kilobar, kilograd, kilogram. These are strictly in accord with the C. G. S. system of units.

To determine relative and absolute humidities, and the temperature of saturation, the so-called dew-point, there is used an equation given by the author in the *Physical Review,* Vol. XIII, No. 4, page 285.

$$p_s = p_e - pC \quad (t - t_e)$$

in which p_s is the pressure of the water vapor at the saturation or dew-point, p_e the pressure of evaporation—that is, the wet-bulb—p the pressure of the atmosphere expressed in kilobars, C a constant, t the temperature of the dry-bulb expressed in kilograds, and t_e the temperature of the wet-bulb.

When the wind velocity exceeds 2 m/s, pC may be written as 0.18; and for purposes of quick calculation we regard it as 20 percent without materially affecting the result.

I stop at this point to read part of a letter just received from Sir Napier Shaw. He says:

> As to the inter-relation of meteorology and oceanography, I think that humidity probably offers the most promising line of attack, if we could be quite certain of getting true humidities on board ship. I suppose that there must be a mathematical expression for the absolute humidity depending upon the air current and the eddy motion which it carries. I could imagine a very useful expedition tracing the increase in absolute humidity down the Trade Wind and ultimately to the West Indies; but it is very difficult to get humidities on board ship because the dry bulb is apt to get wet and the wet bulb to get dry; and both of them to be spoiled by spray. But he will be a great benefactor who will give us a map of the distribution of absolute humidity over the Atlantic Ocean.

Three things in the quotation are important: the suggestion of the map, the expression of belief in the humidity problem as a most promising liaison between meteorology and oceanography, and the remark about the difficulty of getting accurate humidities aboard ship.

Granted, then, that we can get these humidity values at sea with much greater precision by these new instruments, we proceed to use these values in determining the cloud heights.

The temperature of saturation can be obtained without the use of tables, which are always troublesome to use aboard ship, owing to high winds, from the cryoscope, or, if desired, from the accompanying chart (figure 2).

An example will show how this is done.

Let the dry reading be 1063 and the wet, after proper precautions, 1053. The relative humidity is at once shown by the dotted line to be 74, and the dew-point, obtained by running back to left-hand edge of chart parallel to the solid lines, 1046. If the absolute humidity is desired, one has only to follow the 1046 line horizontally to the right-end edge; and one reads 11 grams per cubic meter of space.

We will call 1046 the cloud point or temperature of condensation (heretofore called dew-point, but the new name has some advantages).

What we now want is the difference between the surface temperature

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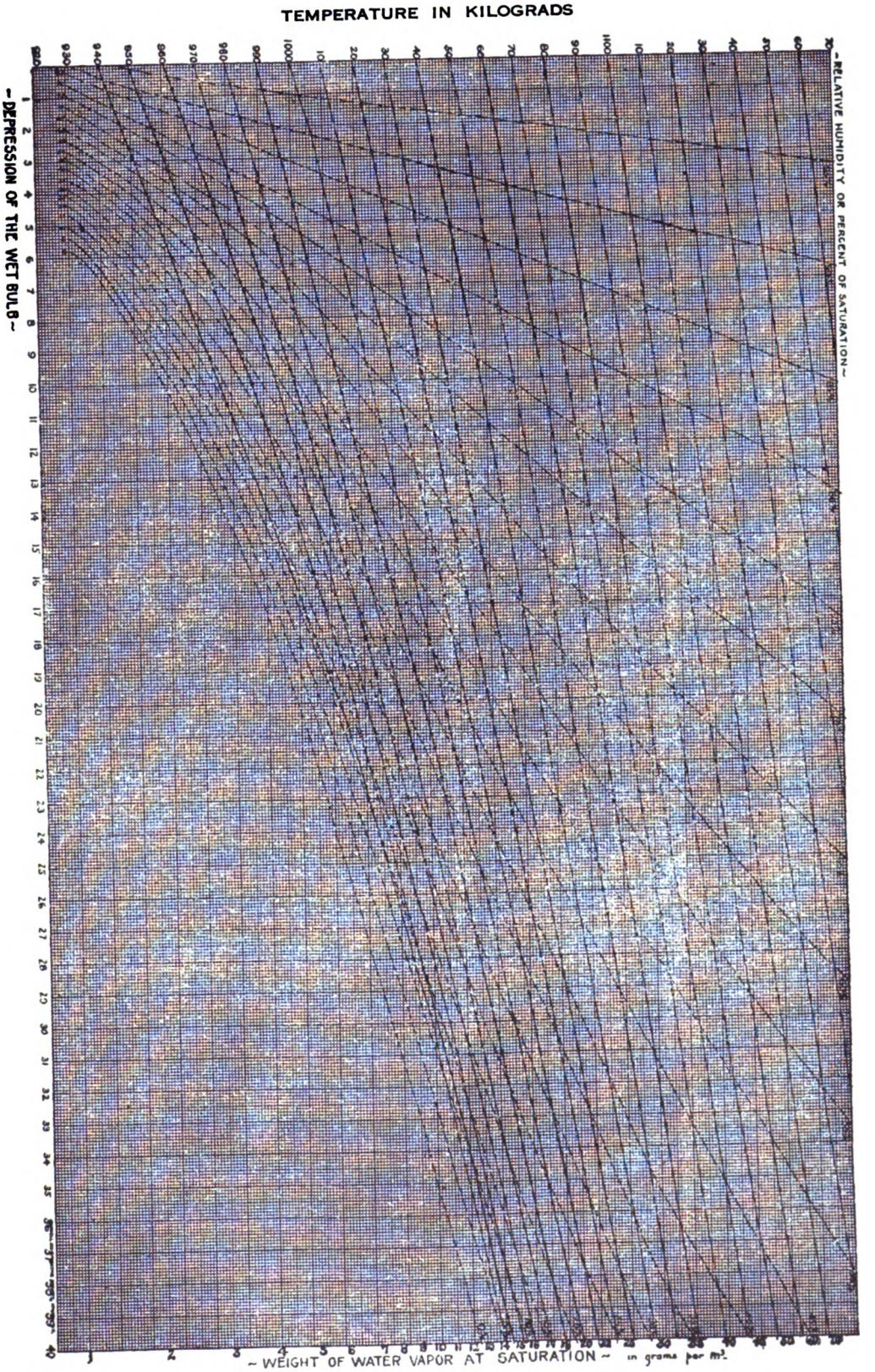
TEMPERATURE IN KILOGRADS
~ DEPRESSION OF THE WET BULB ~
~ RELATIVE HUMIDITY OR PERCENT OF SATURATION ~
~ WEIGHT OF WATER VAPOR AT SATURATION ~ in grams per m³

FIG. 2. Absolute and relative humidity

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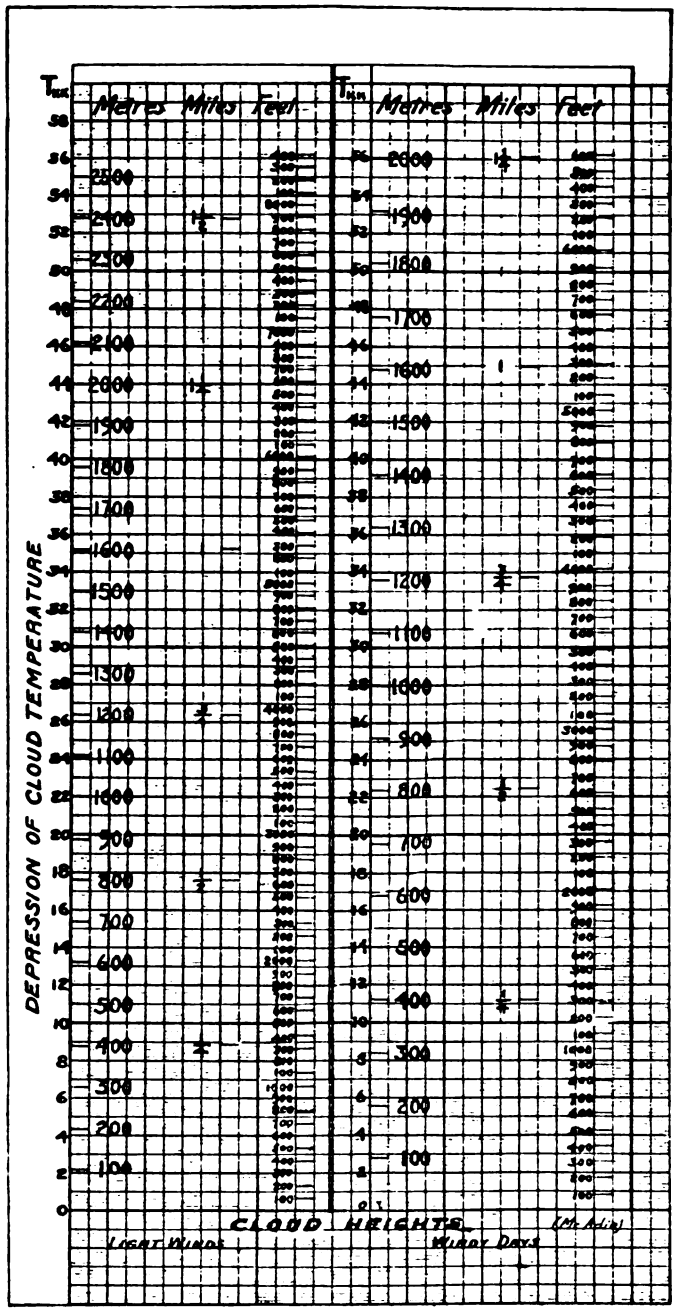

FIG. 3. Cloud heights from surface humidity

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and the cloud level; or what may be called the depression of the cloud temperature (see figure 3). 1063 — 1046 = 17. The cloud height opposite 17 is 750 meters for a day of light winds and 600 meters for a windy day. A correction for percentage of saturation and type of structure is desirable.

The height of the cloud being known, the direction and velocity are obtained as described, and the observer can compare these values with the surface values. Nearly always there will be differences. In fair weather there is generally a steady shifting of the wind to a higher value for both speed and direction. At Blue Hill the mean deviation for the 1000-meter level is 7 grads, or 6 degrees to the right. The increase in speed is variable, often 100 percent in the first 500 meters, and we have instances of 200 per cent. On the land we get all sorts of structures, in some of which, such as sea breeze, the depth of the surface flow is shallow and essentially different from the flow above. The values obtained by this nephoscope-cryoscope method are approximately gradient velocities and directions. It is possible to construct a chart when gradient velocity direction and latitude are known, from which the pressure gradient can be deduced; and thus in a rough way the isolated observer could obtain the curvature of the isobar and pressure tendency. In former years this would have meant much; but now, of course, full reports can be obtained by radio and the surface isobars easily drawn.

It only remains to explain the variation in the value of the lapse rate on different days, or rather with different structures.

While the adiabate rate is 35.5 kilograds per 1000 meters, an average rate of cooling of mixed air and vapor is 21 kilograds.

For moist air saturated, a value of 18 may be taken. In windy weather, a fair value is 25 grads.

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THE STEERING LINE OF HURRICANES

By Alexander McAdie

As a frontispiece to the "Manual of Meteorology," Part IV, "The Relation of Wind to the Distribution of Barometric Pressure," Sir Napier Shaw gives three storm paths of unusual duration and remarkable recurvature (see figure 4).

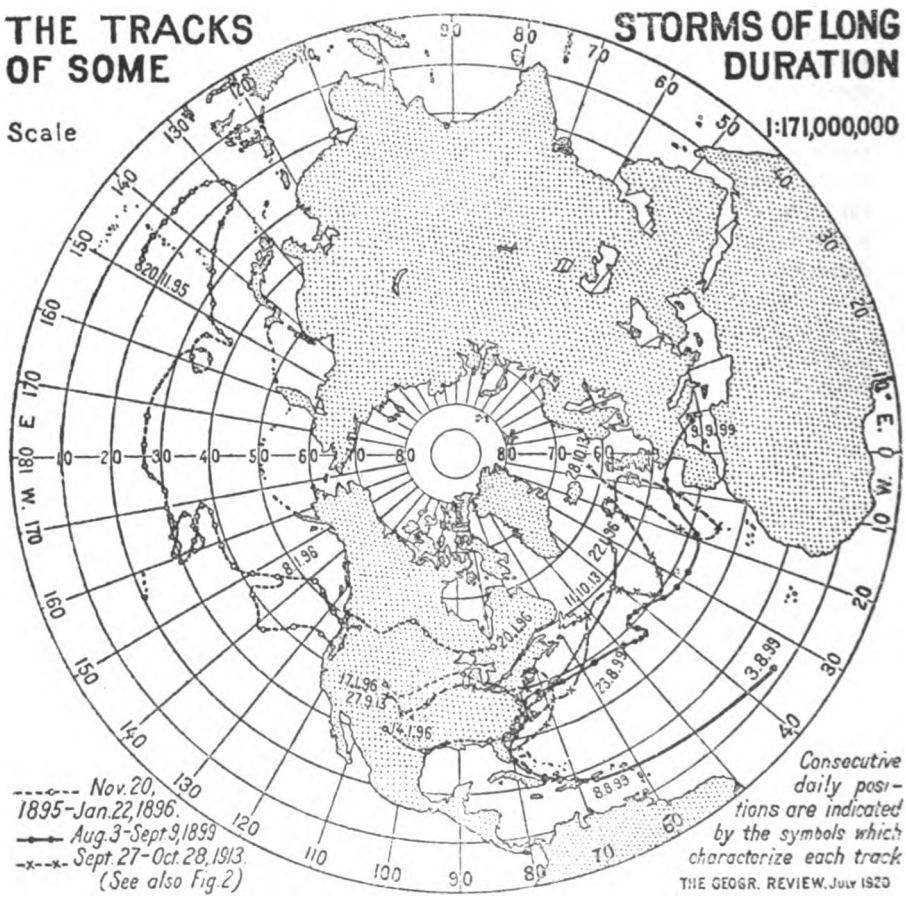
THE TRACKS OF SOME
STORMS OF LONG DURATION
Scale
1:171,000,000
Nov. 20, 1895-Jan. 22, 1896.
Aug. 3-Sept. 9, 1899
Sept. 27-Oct. 28, 1913.
(See also Fig. 2)
Consecutive daily positions are indicated by the symbols which characterize each track
THE GEOGR. REVIEW, July 1920

Fig. 4. The tracks of some storms of long duration (after Shaw)

Perhaps the most striking of these is a track of a typhoon or *baguio* charted by McAdie. This storm path was determined by the usual method of connecting pressure minima. The readings were obtained from abstracts of ships' logs, available through the courtesy of the Hydrographic Office. Surface winds and cloud directions were utilized as much as possible.

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It was assumed that the minimum pressure and the center of circulation as indicated by surface winds were identical. It is, however, to be remembered that the wind direction as noted on the deck of a moving vessel may need correction. Furthermore the center of a cyclone is not necessarily the center of ascending air; and still further there must be in the convergence of the surface winds a certain distortion due to the travel of the storm.

The storms referred to above are perhaps best described in the words of Sir Napier Shaw (page 119).[1]

> There is evident stability in motion of this character because beginning with examples of whirls lasting for some seconds there is apparently an uninterrupted sequence by way of revolving sandstorms or dust-devils, tornadoes, or whirlwinds, to tropical revolving storms and large cyclonic areas with radii of 10 degrees or more.
>
> The only limit of the series is a revolving air-cap covering the hemisphere or a large part of it. And just as a belt of west wind or a belt of east wind may lie over these [British] Islands for weeks, so the other type of quasi-permanent atmospheric motion, which has always been thought of as a column of air in continuous revolution, may preserve its identity for days or weeks. Through the kindness of Professor McAdie of Blue Hill Observatory, Harvard University, we are enabled to give two notable examples.
>
> The first is that of a tropical revolving storm which started on a westerly track toward the Philippine Islands (where visitations of that kind are known as "Baguios"), turned round toward the north and northeast, crossed the Pacific Ocean and, after some vagaries on the North American continent, continued its journey eastward and crossed the Atlantic in the usual track of cyclonic depressions over that ocean. The whole journey lasted from 20th November, 1895, to 22d January, 1896.
>
> The second is a cyclonic depression of October, 1913, in the outer region of which the tornado was formed which caused so much destruction in South Wales on the 27th of that month.[2] The track of the main depression shows an anomalous path from Canada to the north of the British Isles. [See figures 4, 5, and 6 from the "Geographical Review."]
>
> To these notable examples has been added the long track of cyclonic depression which was figured in the Meteorological Office chart of the North Atlantic and Mediterranean for August, 1904.[3] The cyclone was first noted on 3rd August, 1899, in that part of the North Atlantic Ocean where West Indian hurricanes often take their rise. It moved westward to the West Indies, skirted the coast of Florida and turned eastward over the Gulf Stream. After some hesitation about latitude 40° W. it made for the mouth of the English Channel and, missing that, crossed to the Mediterranean, where it lost itself on 9th September, after a life of thirty-eight days.

In each of the above described storms it is evident that causes other than those developed by the rotating mass of air, operated to retard these storms in their eastward progress.

Let us now trace the path of a West Indian hurricane where the evidence is seemingly more direct.

On the morning of October 15, 1910, this storm was centered between Havana and Key West moving very slowly northward. The maximum wind velocity at the former place was 39.4 m/s (88 miles per hour); on the a. m. of the 14th; and at Key West 26.8 m/s (60 miles per hour).

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[1] See also "Wandering Storms," McArdie, *Geographical Review*, 10, no. 1, July, 1920.

[2] *Geophysical Memoirs*, no. 11. M. O. Publication, no. 22a.

[3] M. O. Publication, no. 149.

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FIG. 5. Track of storm of September 27–October 28, 1913.

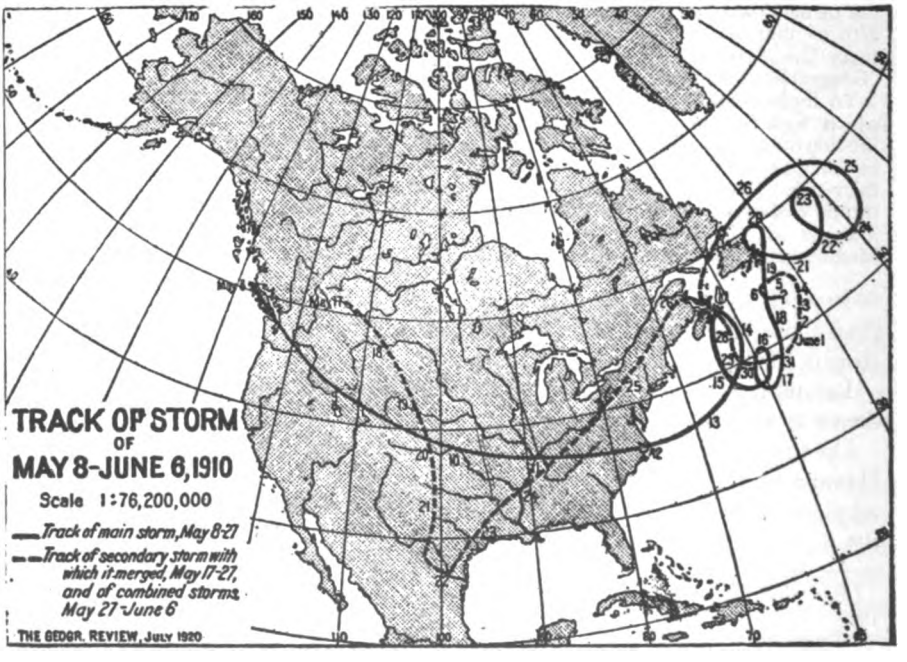
TRACK OF STORM
OF
MAY 8-JUNE 6, 1910
Scale 1:76,200,000
Track of main storm, May 8-27
Track of secondary storm with which it merged, May 17-27, and of combined storms, May 27-June 6
THE GEOGR. REVIEW, JULY 1920

FIG. 6. Track of storm of May 8–June 6, 1910.

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The storm's progress northward was checked by a continental area of high pressure moving southward. Thus on the 17th we find the hurricane actually *retrograding* and centering again over Havana. As the continental anticyclone moved east, the hurricane developed a northerly component of motion and on the 18th moved across Florida. It then followed the usual hurricane track passing south of Cape Hatteras on the 20th. The hourly speed increased from 30 kms. to 50 kms. per hour and the direction of motion 40 degrees east of north.

The speed continued to increase averaging 60 kms. per hour and the direction shifted more to the east, approximately 65 degrees east of north, and so at noon of October 21 the center was in the latitude 37 degrees north and 67 degrees west.

Professor Bjerknes has remarked that "anticyclones are born as cyclones die" but the behavior of this and similar storms gives the impression that the path and speed of West Indian hurricanes, off the coast of Florida, are dependent upon the intensity and direction of advancing highs. These in turn may be but the surface expression of an advancing polar front.

Two types of south moving sub-Arctic surges which seem to control the path of hurricanes from the Caribbean Sea to the North Atlantic can be identified. The first of these is a Nichikun high. This is a more appropriate designation of what has heretofore been known as a Labrador high. According to Dr. Klotz [1] there is nowhere else in Canada "so distinct a Pamir or Roof of the World as the neighborhood of Lake Nichikun (in English, Otter Lake)." The lake itself is in latitude 53° N., longitude 71° W., and on the northwest slope of the Height of Land. The drainage is into Hudson Bay. On the south and east the drainage is into the River St. Lawrence. It is this southern slope which concerns us because south moving masses of air pass over the ridge, elevation 730 meters; and being both cold and dry and therefore heavy, fall to sea level in a comparatively short distance, 200 to 600 kilometers.

The other type of sub-Arctic surge is the "Labrador," essentially oceanic.

Both of these tongues may be portions of what Bjerknes has called the polar front. They undoubtedly play an important part in determining the speed and path of storm centers in the North Atlantic States and effectively control the path of tropical storms or hurricanes as they move from the south and change into North Atlantic cyclones.

On the Pilot Chart of the North Atlantic Ocean for October, the path of the hurricane under discussion ends abruptly in the position and on the date given above (Oct. 21). One might in consequence infer that the storm dissipated at sea.

Careful study of pressure conditions shows a depression on the 22d in latitude 35° N. and longitude 60° W. A day later it appears as one of two centers in a large depression extending from New Brunswick to

[1] In a letter to the writer.

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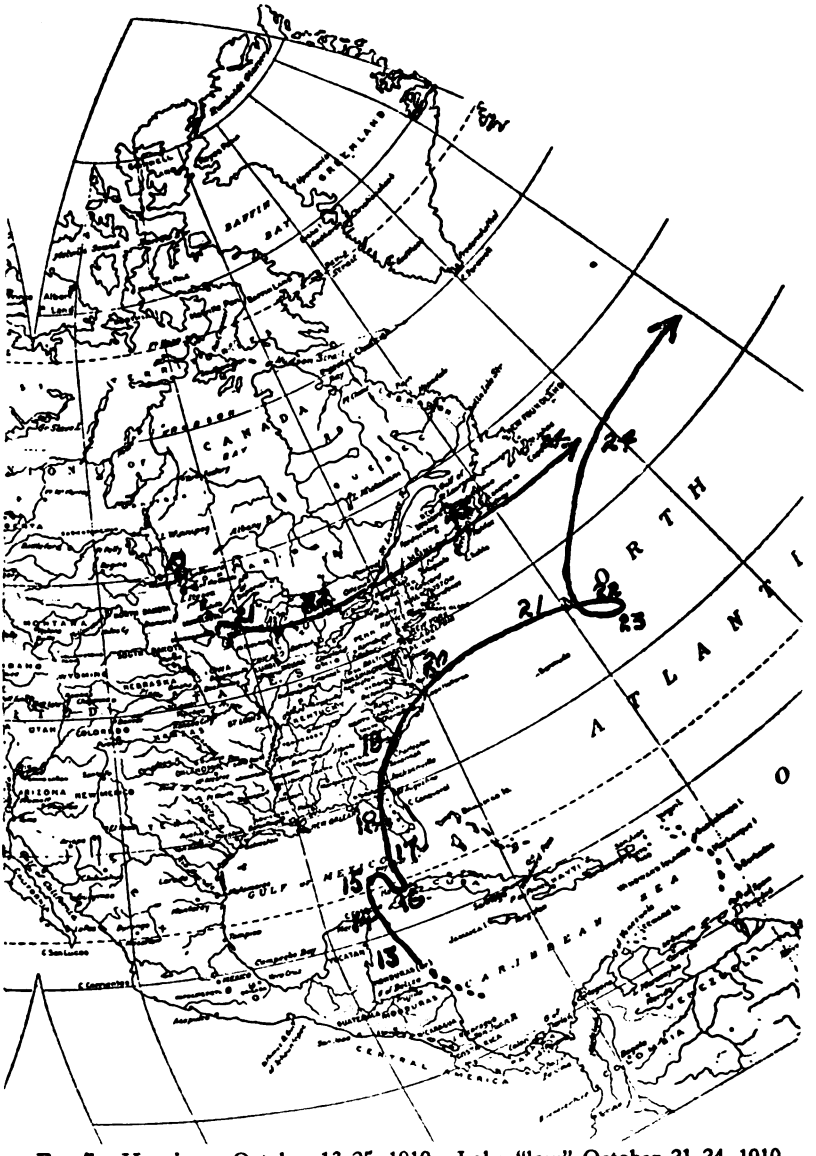

FIG. 7. Hurricane October 13–25, 1910. Lake "low" October 21–24, 1910. (Based on an equal area projection devised by B. J. S. Cahill)

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Bermuda. The other center can be traced back to a storm over Lake Superior on October 21. The previous history of this depression, while somewhat obscure, is deserving of study. It appeared as an unexpected abnormal development and invalidated all forecasts made for the Lake Region, Upper Mississippi and Ohio Valleys. Where cold weather, frosts and an absence of precipitation were reasonably anticipated from an advancing high pressure (1030 kb.), there suddenly developed warmer weather with rain. On the face of the map we are unable to connect this low with a more northern slow moving depression of the Alberta type. The weather map of October 20, 1910, will repay study in connection with the steering line of cyclones.

To return to the hurricane and its further history, we have seen that when centered over Florida, there were in juxtaposition two air masses of different origin, one from the tropics with a vapor content of not less than 20 grams per unit volume (one cubic meter of space) and an average northwest speed of one kilometer per hour, while the other air mass was of sub-polar origin, approximately 20 kilograds (5.5 degrees C.) colder, and with an average vapor density of 12 grams per cubic meter. The densities of the two air masses at a pressure of 1 megabar would be approximately 1170 and 1220 grams. Air motion is initiated by difference of pressure rather than difference of density; but it is plain that the south moving air mass would continue to gain momentum and underrun the less dense northbound air. The horizontal pressure gradient was 1 kb./20 km. and hence surface velocities of 30 meters per second or higher would and did occur. The gradient velocities were 23 m/s or higher; and the radii of survature of isobars approximately 100 kilometers.

Figure 7 shows the path of the hurricane from October 13 to 25, and also the path of the lake "low" from October 21 to 24. Other charts show the surface pressure distribution on various dates.

It is much to be regretted that there are no records of winds aloft. When such data shall be available then perhaps definite relations between path, velocity and duration of hurricanes with upper winds will be forthcoming.

Recently it has been claimed by meteorologists of the Bergen (Norway) Institute that the storms of the Northern Hemisphere can be traced back to a "surface of junction of polar and equatorial air." This surface can be detected at the ground as "a line of discontinuity" in surface conditions. In other words, it is the boundary between air masses of different densities, pressures, and vapor content.

Given then a mass of warm moist air moving north of east, under the combined effects of general drift, pressure gradient and rotational deflection, and a second mass of cold dry air moving south, the surface of discontinuity should be detectable as a moving front.

Professor Bjerknes has come to the conclusion from the study of the structure of moving cyclones that a broad belt of rain accompanies the moving (and ascending) warm moist air, and a second smaller rain belt

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follows, where cold dry air underruns the warm air, that is, along the wind shift or squall line.

A more important point, however, is the discovery through the use of detail maps, that the discontinuity or contrast can be traced from any cyclone to another. As expressed by Bjerknes, cyclones follow each other along a common line of discontinuity like "pearls on a string."

Furthermore this line of discontinuity surrounds the polar regions as a closed circuit. It shows how far the cold air flowing along the ground has penetrated. Shaw describes it as a kind of *polar front line*.[1]

The following substance of the discussion at the Meteorological Office on "new methods of forecasting" may make plain the leading features of Bjerknes's views.[2]

> In the case of a cyclone making progress towards the east, a sector to the south is occupied by a warm current; this warm area on the earth's surface is bounded to the north by the "steering line," to the west by the "squall-line." Bjerknes' generalization is "that these squall-lines and steering lines of all the cyclones of the northern hemisphere are parts of a single line—the polar 'front.'" We are to think of two great streams of air, both flowing from the west, the more northerly stream being colder and carrying less moisture. The boundary between these two streams is unstable and its oscillations manifest themselves as cyclones. The warm stream overrides the cold one, which retaliates, so to speak, by turning round and kicking its partner in the back.

Charts 4, 5 and 6 are reproduced through the courtesy of the *Geographical Review*, published by the American Geographical Society, New York City.

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[1] *Nature*, January 24, 1920, p. 524.
[2] *Meteorological Magazine*, November, 1920, p. 213.

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TRANSACTIONS
OF THE
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BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

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FOURTH ANNUAL MEETING, APRIL, 1923
WASHINGTON, D. C.

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GENERAL ADDRESSES

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THE ORGANIZATION AND AIMS OF THE AMERICAN GEOPHYSICAL UNION[1]

LOUIS A. BAUER, *Chairman*

I. HISTORICAL

This is the fourth annual meeting of the American Geophysical Union, as such, although on June 24-25, 1919, there was held a preliminary meeting of a tentatively organized "American Section of the proposed International Geophysical Union," then in process of formation under the auspices of the International Research Council, which, as will be recalled, was established in 1918, when the world conflict was drawing to a close. However, the concept of our Union may trace its origin even prior to the formation of the International Research Council and of the present International Geodetic and Geophysical Union. For soon after the establishment of our National Research Council in 1916, the chairman, Dr. Hale, requested the writer to prepare a memorandum respecting provision to be made for certain geophysical sciences. To quote from this memorandum but one sentence germane to our topic today—"It would appear that great opportunities are before us to make our influence felt in the world-sciences, by which are meant those subjects of research which embrace the Earth, or even the Universe, within their legitimate provinces." In subsequent correspondence with Dr. Hale it was suggested that the term "geophysics" be understood to include geodesy, geological physics, meteorology, terrestrial magnetism, terrestrial electricity, seismology, tides and oceanography; and it was recommended that there be formed a special committee of the Council, or a subcommittee of physics dealing specially with "world physical sciences."

To stimulate further interest in the subject, at the joint meeting in 1916 of the American Physical Society and the Section of Physics of the American Association for the Advancement of Science the speaker presented a paper entitled, "Our part in the Advancement of World Physical Sciences."

It will be seen from these references that the general idea was the formation of a body similar in its organization and aims to those

[1] As presented at the opening general session of the annual meeting of the American Geophysical Union at Washington on April 17, 1923, with some slight additions. The review was prepared in compliance with a request made at the closing session of the annual meeting of the American Geophysical Union in 1922, and in answer to inquiries from members as to the precise status of the Union, especially with regard to its origin and development and its present relations to the National Research Council and to the International Geodetic and Geophysical Union.

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embodied in the statutes of the present International Union and, in particular, of our own Union. The chief desire as expressed in these early documents was to provide a meeting-ground for those working, more or less independently, on geophysical subjects having points of contact and common interests. This was accomplished later in Great Britain by the appointment in July 1917 of a special committee on geophysics of the British Association for the Advancement of Science.[2]

The council of our National Academy, however, was not yet prepared to recognize the need of a special body for geophysics alone, and considered that the desired object could be attained by merging geophysics with geography, and accordingly four of the present members of the American Geophysical Union became members of the Geography Committee, under the chairmanship of Professor William Morris Davis. But soon after geophysics received a more distinctive recognition, being specifically mentioned in the title of one of the most important divisions of the war organization of the National Research Council, namely, the "Division of Physics, Mathematics, Astronomy and Geophysics." It was the writer's privilege to serve as a member of that division, under the chairmanship of Dr. Robert A. Millikan, throughout our participation in the war.

Then came the close of the war and with it a reorganization of the National Research Council on a peace basis. One of the live questions was how best to secure representative membership for the various divisions: Physical Sciences, Chemistry, Geology, etc. The solution of this problem was comparatively easy for the sciences which had national societies. Thus the Division of Physical Sciences would be recruited from time to time by representatives recommended to the National Research Council by the American Physical Society, the American Astronomical Society, the American Mathematical Society, etc. But how were the geophysicists to be represented? For seismology, there was the Seismological Society of America, and for meteorology, there was at that time in process of formation what has

[2] The British Geophysics Committee had its first meeting in November 1917, in the rooms of the Royal Astronomical Society at Burlington House, London. Since then there have been "Geophysical Meetings" about once a month during each year from about October to May. The topics discussed have covered every branch of geophysics and the leading men of science in Great Britain, interested directly or indirectly in geophysics, have participated. Abstracts of the papers and discussions are published in the British monthly journal, *The Observatory*. Some of the papers have been published in the Geophysical Supplement of the *Monthly Notices of the Royal Astronomical Society*. Three of these "Supplements" have thus far appeared, namely for March 1922, January 1923, and May 1923.

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since become the American Meteorological Society. But there were no distinct national societies for geodesy, terrestrial magnetism and atmospheric electricity, volcanology, oceanography, and geophysical-chemistry. To be sure, quite a goodly number of geophysicists were members of the national societies devoted to physics, astronomy, mathematics, geology, and geography. Hence, to a limited degree, representation on a Geophysics Committee of the National Research Council could be obtained from certain existing societies, and the number of representatives thus secured could be supplemented by the National Research Council through choosing members at large, interested in branches of geophysics not distinctly recognized by the existing national societies.

Finally, in February 1919, Dr. Hale, as Chairman of the National Research Council, appointed a small committee to consider the question of the organization of an "American Section of the proposed International Geophysical Union," and the chairman of the committee, Dr. R. S. Woodward made a report, which as it is brief, yet full of interest at the present time, we shall quote here in its entirety:

"MARCH 4, 1919.

"To the Chairman of the National Research Council:

"Your Committee appointed to consider the question of a logical and practicable organization of the proposed American Section of the International Geophysical Union respectfully submits the following report:

"The earth is at once the subject and the object of many sciences. Of these the most important are Astronomy, Geodesy, Geology, Meteorology, Seismology, Terrestrial Magnetism, Terrestrial Electricity, Tides, and Volcanology.

"While each of these sciences is more or less distinct in itself, they are closely related to one another, and progress in any one of them may be expected to depend to a great extent on the general progress attained in the others. Each of these sciences has its devotees and its experts, and the number of these in the aggregate is now very large. Hence in any scheme of effective organization it is essential to secure groupings of these various subdivisions of geophysics in order that the number of groups may not be too unwieldly in the transaction of business essential to such organizations. But it should be distinctly understood that in recommending a limited number of groups for purposes of administration it is not desired to discourage relations of closest reciprocity between the devotees to the various sciences included in the groups. On the contrary, it is the opinion of your Committee that progress in the future is most likely to result from active cultivation of the borderlands that now serve to distinguish, but only indefinitely, the several fields of geophysics.

"It should be understood also that the groupings recommended are to be regarded as provisional and subject to such changes as future experience may suggest. It is recognized also that the groupings here recommended may not be the most appropriate for all countries or possibly for an international organisation, since much regard should be given in all such matters to historical precedents and to the circumstances presented at any epoch by individual investigators, and especially by governmental organizations, of any country.

"With these reservations the Committee recommends that the following groups

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of subjects should be recognized in the organization of the American Section of the International Geophysical Union:

"Group 1. Geodesy. This group may be assumed to deal with questions concerning the size, the shape and the mechanical properties of the earth.

"Group 2. Seismology and Volcanology.

"Group 3. Meteorology and Mareology, including especially all questions presented by the mechanical properties of the atmosphere and the oceans.

"Group 4. Terrestrial Magnetism and Terrestrial Electricity. This group is intended to deal with the magnetic and the electric properties of the earth, including its atmosphere.

"The Committee recommends that initially the designation of members to constitute the proposed Geophysical Section be made by the National Academy of Sciences. It is further recommended that in making such designations regard be had to the desirability of securing representatives from the following Government Bureaus:

Bureau of Fisheries
Bureau of Mines
Bureau of Standards
Coast and Geodetic Survey
Hydrographic Office, U.S.N.
Geological Survey
Weather Bureau

"Similarly, the Committee suggest that representatives also may be fitly chosen from the following national societies:

American Astronomical Society
American Mathematical Society
American Physical Society
Geological Society of America
Seismological Society of America

"The Committee further recommends that in order to promote research and discovery in geophysical science in general, steps be taken by the American Section of the International Geophysical Union toward the formation of a new society to be called the American Geophysical Society.

(Signed) "R. S. WOODWARD,
"For the Committee."

At a meeting of the Executive Committee of the Division of Physical Sciences, March 10, 1919, the organization and initial membership of an American section on Geophysics were approved, and soon after were also approved by the National Academy of Sciences. The exact designation of subjects to be included in the various groups was deferred, however, until after the Brussels meeting in July 1919 of the International Union. The question of the establishment of a geophysical society was also referred for settlement to the Geophysical Section after its permanent formation. Messrs. William Bowie, Louis A. Bauer and C. F. Marvin were made members of the Division of Physical Sciences to represent Geophysics.

Four meetings of the Provisional Executive Committee of the Geo-

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physical Section were held in May and June 1919 and on June 24 and 25 the Section was tentatively organized, Dr. William Bowie acting as chairman. Permanent organization was deferred until after the Brussels meeting. The Section accepted the proposal to be the Geophysics Committee of the Division of Physical Sciences, and decided to concern itself with national as well as international problems in geophysics. At this meeting delegates were appointed to the Brussels meeting and resolutions were passed respecting various matters pertaining to the organization and sections of the proposed International Union. The delegates were also constituted a committee to draft a plan for permanent organization of the American Section after the Brussels meeting.

On November 13, 1919, the secretary of the tentative American Section transmitted to the members "Proposals for the Permanent Organization and Statutes of the American Geophysical Union," prepared by a sub-committee, after giving very careful consideration to the following points: (1) The structure and Statutes of the International Research Council, and of the International Geodetic and Geophysical Union, definitely formed at Brussels in July 1919; (2) the present relations of the existing "American Section of the proposed International Geophysical Union" to the National Research Council, and the relations considered desirable in future; and (3) the views expresseed by present members, especially at an informal conference of the Committee of the Brussels Geophysical Delegates with members of the "American Section" who reside in or near Washington. The said conference was held on October 31, 1919, at the office of the National Research Council. Furthermore, in drafting the "proposals," the sub-committee had the benefit of extended conference with Dr. C. E. Mendenhall, at that time Chairman of the Council's Division of Physical Sciences, and of Dr. Henry S. Washington, both of whom were present at Brussels.

The secretary, Dr. Harry O. Wood, further stated in his transmitting letter:

"The present status of the 'American Section' is that of a *committee* of the Division of Physical Sciences of the National Research Council. This status it will retain until it is discharged as such, or until it is superseded by the adoption, as of some definite date, of proposals for permanent organization which change its status. In this connection it has seemed best to the committee on organization to recommend that the proposed 'American Geophysical Union' be made a Committee of the Council, as a whole, and that the 'Union' be so constituted as to *unite and co-ordinate* in our country the interests of physics, chemistry and geology in geophysical questions.

"The name 'American Geophysical Union' was settled upon as the result of careful consideration and evolution of various preliminary drafts. Thus, instead

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of 'Union' it was originally proposed to use the term 'Committee,' and later 'Commission'; however, as progress was made in drawing up the proposals, the need of a more appropriate term became evident. Thus, the 'American Geophysical Union,' as proposed, is a union of two distinct committees, namely, the American 'National Committee' of the International Geodetic and Geophysical Union, and the Committee on Geophysics of the National Research Council. In the absence of an American Geophysical Society in the United States, the proposed 'Union' would seek to bring together and co-ordinate all societies, bodies, and institutions in the United States interested in geophysics."

The "Proposals," having received the unanimous approval of the members composing the former "American Section," were approved by the Executive Board of the National Research Council on December 20, 1919. On February 14, 1920, the American Geophysical Union was made a committee of the Executive Board of the Council, and the first meeting of the Union was held on April 23, 1920. Dr. William Bowie, who had been acting chairman since 1919, was elected chairman of the Union for the statutory two-year period 1920-1922.

II. ORGANIZATION

These introductory remarks will suffice to show the initial difficulties encountered and how, in consequence, there was gradually developed the "American Geophysical Union," which has the unique distinction of being like no other body of the National Research Council. During 1919 and 1920, we were attached to the Division of Physical Sciences as the National Geophysics Committee, just as are the national committees for astronomy, mathematics and radiotelegraphy. However, we proved ourselves too lusty an infant for in membership we outweighed the entire Division. Then again the Council soon found that Geophysics was of so wide a scope that its points of contact were not simply with one division, but with several. And so finally in 1920 we were made one of the Technical Committees under the direct parentage of the Executive Board of the Council. But our woes did not end there, for at that time we had no representative voice on the Board and as the membership of the Board changed from year to year, we suffered the natural consequences resulting from variable parentage. Just as our parent towards the end of his year's membership on the Board would become truly sympathetic with our aims and alive to our needs, he would be succeeded by a new parent and the process of enlisting interest had to be begun all over again.

Fortunately, although our Union, unlike other national bodies and other sciences, still has no direct representation on the Council's Executive Board, it has certain ex-officio members on its Executive Committee; namely, the chairmen of the following divisions of the

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Council: Foreign Relations, Physical Sciences, Chemistry and Chemical Technology, Geology and Geography, and Biology and Agriculture. We must depend upon these ex-officio members, who also, in general, vary from year to year, for representation at the meetings of the Executive Board of the Council. During previous years it was only rarely, for one reason or another, that one of the ex-officio members was present at the monthly meetings of our Executive Committee. During the present fiscal year, however, there has been an exceptionally faithful attendance on the part of some of the ex-officio members.

We also, in our entirety, proved too "bulky" as a committee of the Executive Board, especially when it came to the matter of the possible moral obligations involved to provide traveling expenses for every member of the Union coming to the annual meetings. Hence, in the spring of 1921, the relation of the American Geophysical Union to the Council was changed so that the Union as a whole was replaced as the Committee on Geophysics of the Executive Board of the National Research Council by the Executive Committee of the Union. The Union, as a whole, however, continues to be the American National Committee of the International Geodetic and Geophysical Union.[5] Although not every member of our Union is recognized now as a member of the National Research Council, it is the Union as a whole which nominates to the Council the members of the Executive Committee of the Union.

In other words, the American Geophysical Union is now virtually on the same footing as existing national societies, which choose and recommend to the National Research Council their representatives for the various divisions and committees of the Council. While we still recognize the sponsorship of the Council, in that we submit to it for approval any amendments to our statutes or additions to the membership, it is not believed that the Council would interpose any objections if we thought it desirable to form ourselves into a national geophysical society. As has been shown, in many respects we are already essentially such.

According to action taken at the annual meeting in 1922,[6] our permanent membership was limited to 75, subject to future change as circumstances required; there are at present 65 members, widely distributed geographically, even Hawaii being represented.

Whether the time is ripe to constitute ourselves into an "American Geophysical Society," or whether we should retain the present name

[5] See Sixth Annual Report of the National Research Council, p. 6; and minutes of the Executive Committee of the American Geophysical Union, May 7, 1923.

[6] Also confirmed at the annual meeting in 1923.

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"American Geophysical Union" and the present organization as indicative of a union or confederation of geophysical sciences, and alter or expand our organization and membership, is a matter for discussion. If we follow the type of organization as represented by a society, we may readily include in the membership citizens of other countries than the United States. In accordance with a recent action taken by the Executive Board of the National Research Council, "membership in the Council shall be limited to citizens of the United States. This, however, shall not be construed as applying to membership on committees appointed by or acting under the Council whose members are not necessarily members of the Council; provided that members not citizens of the United States shall in no case form a majority of any such committee.[5] The majority of our Executive Committee and of chairmen of sections must accordingly be citizens of the United States.

III. OBJECTS

Quoting from the statutes[6] as adopted in 1919 and amended to May 1923:

Preamble.—"The American Geophysical Union is hereby established by the National Research Council. It supersedes the 'American Section of the proposed International Geophysical Union.' The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council."

Objects.—(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and co-ordinate researches which depend upon international co-operation, and to provide for their scientific discussion and publication; and to facilitate special researches, such as the comparison of instruments used in different countries.

(b) To promote and co-ordinate the study of the various branches of geodesy and geophysics in the United States of America and its outlying territories."

A review of the work and functions performed by the Union, since its existence, would show that the objects just stated have steadily been kept in mind and that we have taken our part, as fully as circumstances permitted, in the promotion of international and national projects pertaining to geophysics, in general. From time to time we have furnished information solicited by the National Research Council and International Geodetic and Geophysical Union, and have reviewed proposals submitted to us by or through the Council.

The American Geophysical Union may justly lay claim to having

[5] Action of Executive Board of the National Research Council, February 13, 1923.

[6] See pages 24 to 26.

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taken a leading part in the initial recognition, at the organization meeting of the International Geodetic and Geophysical Union at Brussels in 1919, of the chief branches of geophysics, and in the establishment of sections pertaining thereto. Prior to the formulation of resolutions passed at the spring meeting in 1919 of our preliminary organization, the International Research Council at first favored the adoption merely of sections of geodesy, meteorology and seismology by the proposed International Geophysical Union. The American delegates, however, acting in accordance with the conclusions reached at the preliminary meetings in Washington, of the "American Section" and on the basis of the information at hand, advocated the immediate establishment of the following sections: Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Volcanology, and Oceanography. And the American view finally prevailed at Brussels as the result of various preliminary meetings of our delegates with those from other countries represented. It was a matter of keen regret to the American delegates, as well as to those of other countries, that the briefer and more logical designation, "International Geophysical Union," as originally proposed, was not finally adopted by the International Research Council, in deference to the wishes of one country.

Five members of our Union are at present officers of the International Geodetic and Geophysical Union, viz: Messrs. Bauer, Bowie, Littlehales, Marvin and Washington, and, accordingly they are also members of the Division of Foreign Relations of our National Research Council. Furthermore various members of our Union are members of committees of the sections of the International Union.

In the matter of arousing renewed interest in the scope of geophysical sciences, and in the unusual opportunities for important and fruitful research, our Union has already done much, through its meetings and publications, though more remains to be done. The observational and investigational work in the various branches of geophysics in the United States is being largely done at present by governmental bureaus and certain research institutions, though notable work is to be credited also to investigators connected with some of our universities. It is believed, however, that the endeavor should be made to enlist the help of still more university men, by presenting in as concrete a form as possible definite problems awaiting experimental and theoretical investigation. During the war we were fortunate in the number of university men who found opportunity for their activities and participation in war investigational work pertaining to various branches of geophysics, notably meteorology. But

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as soon as the war ended their interests waned and it behooves us to find new ways of re-stimulating them.

IV. FUNDS

The funds required for the maintenance of the American Geophysical Union, especially in connection with the annual meetings, averaging about $1,000 per annum, are provided by the National Research Council. The Council, through its Division of Foreign Relations, made provision in part for the payment of the expenses of some of the delegates to the Rome 1922 meeting of the International Geodetic and Geophysical Union. During the first year of the existence of The International Geodetic and Geophysical Union, the annual dues for the United States were paid by the National Research Council from special funds received for the payment of annual dues of the established international unions. In the following years, however, the annual dues have been paid by Congressional appropriation in the Diplomatic and Consular bill of the State Department, there being included in this appropriation also the dues for the International Research Council and unions established by it. The Council has also borne the expense of publication of papers and reports by the Union.

V. CHARACTER OF ANNUAL MEETINGS

The character and purpose of our annual meetings has naturally varied from year to year in accordance with circumstances. The meetings of 1920, 1921, were largely concerned, as is the present meeting, with submission and discussion of special reports and papers. The meeting of last year was chiefly devoted to the discussion and preparation of reports relating to the Rome meeting of the International Geodetic and Geophysical Union in May 1922.

Our programs of this year for each of the sections are replete with interest, and while the Committee on Meetings has laudably endeavored to arrange the meetings of the several sections so as to avoid conflicting interests as much as possible, one might, nevertheless, wish that it were possible to have all papers and reports presented at general meetings of the entire Union. There might be held, however, brief sessions of each section for the transaction of strictly business matters and for the presentation of purely technical reports and papers. We may be in danger of losing the chief advantage of our annual gatherings if we do not find it possible to make provision in future for more general sessions to which all papers, or at least the chief ones, would be presented and then afford ample opportunity for discussions, conferences, or symposiums, on mooted questions, not

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infrequently of interest and importance to several of the sections, and possibly to all of them.

VI. SECTIONS AND COMMITTEES

Perhaps some consideration may have to be given in the near future as to how best to avoid the dangers arising from possible over-organization and too intense sub-division into groups and committees. One of the chief objects of our Union from the very beginning has been, as already stated, to provide a common meeting-ground, or clearing-house, for our varied aims and researches, with the minimum amount of machinery or organization.

Not all national committees have as yet formed themselves into sections corresponding in general to those of the International Geodetic and Geophysical Union, as Belgium, Canada, France, Japan, Spain, and the United States have done. However, national committees in most countries are composed of less than twenty-five persons, so that splitting up into sections might not be advantageous. The status of the American Geophysical Union, as already explained, is somewhat different from that of other national committees. For, in the first place, in order to have adequate representatives of the greatly varied interests in geophysics over the entire extent of the United States and outlying territories, it has been necessary to have in our Union about three times the average membership of national committees. In the next place, we have endeavored to unite in our Union the objects of both a national committee and a national geophysical society.

It is of interest to note the provisions for geophysics made by progressive Japan. The National Research Council of Japan consists of about 92 members, grouped into the following 9 divisions: General Affairs, Astronomy, Geophysics (10 members), Chemistry, Physics, Geology and Geography, Biology and Agriculture, Medical Sciences, and Engineering. In addition to this Division of Geophysics, which is on equal footing with the other divisions, there is a "National Committee for Geodesy and Geophysics," consisting of the 10 National Research Council members of the Division of Geophysics, and 13 co-opted members, who are not members of the Council. The chairman and vice-chairman of both the Division of Geophysics and of the National Committee are, respectively, Professor A. Tanakadate and Professor K. Nakamura.[7]

In conclusion, permit me to advert to a question raised in our pioneer days, as to whether an organization like ours, composed of so

[7] National Research Council of Japan, Proceedings, No. 1, March, 1922, pp. 16-21.

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many different groups and devoted to such a variety of world-embracing subjects, which to some appeared but slightly related, could find sufficient points of interest to avoid disintegration and splitting up into several organizations. But our Union has held together and promises still to hold together.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D.C.

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ORGANIZATION AND AIMS OF THE NATIONAL GEODETIC AND GEOPHYSICAL COMMITTEE OF CANADA[1]

NOEL OGILVIE, *Superintendent, Geodetic Survey of Canada*

Dr. E. Deville, Chairman of the National Committee of Canada of the International Union of Geodesy and Geophysics, received a letter dated April 4, 1923, from Dr. Louis A. Bauer, Chairman of the American Geophysical Union, advising him that arrangements had been made to allow time at this meeting for the presentation of an address on "The Organization and Aims of the National Geodetic and Geophysical Committee of Canada." This honour Dr. Deville has kindly conferred upon me and it gives me great pleasure to be with you and to present this address on behalf of the National Committee of Canada.

The National Committee of Canada, of the International Union of Geodesy and Geophysics, was formed by the Honourary Advisory Council for Scientific and Industrial Research, and I received a letter from Dr. A. S. Macallum, the Administrative Chairman, dated the 23d of April, 1920, reading as follows:

"I have the honour to inform you that you have been appointed a member, ex officio, of the National Committee for Canada of the International Union of Geodesy and Geophysics, the other members of which are as follows:

The Director of the Dominion Observatory, ex officio
The Surveyor-General, ex officio
The Director of the Meteorological Service, ex officio
The Director of the Geological Survey, ex officio
The Superintendent of Tidal and Current Surveys, ex officio
The Chief Hydrographer of the Naval Service, Department, ex officio
Four representatives of The Royal Society of Canada.

"The appointment of the representatives of The Royal Society of Canada will probably be made at the meeting to be held in the third week of May.

"As soon as these representatives are appointed a meeting of the Committee will be called by Dr. Deville, who has been appointed Convener."

At a meeting held on May 20, 1920, the following four representatives of The Royal Society of Canada were appointed and their names added to the list of members of the National Committee of Canada of the International Union of Geodesy and Geophysics:

Professor L. B. Stewart, University of Toronto
The Seismologist, Dominion Observatory
C. A. French, Magnetician, Dominion Observatory
Professor R. W. Brock, University of British Columbia.

[1] Presented at the Annual Meeting of the American Geophysical Union in Washington, April 17, 1923.

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Dr. Deville was elected Convener of this Committee and his first duties were the preparation of the By-Laws and Regulations governing the work.

A preliminary and organizing meeting of the National Committee of Canada was held at the Geographic Board rooms, Ottawa, on Tuesday, May 25, 1920. Dr. Deville was made Chairman of the National Committee and Mr. C. A. French was made Secretary.

At this meeting Dr. Deville gave a detailed account of the genesis of the International Research Council, the General Assembly of which was held at Brussels during July 1919, and the subsequent formation of the International Union of Geodesy and Geophysics, reading the essential extracts from the constitution and statutes of the Council and of the Union, pointing out especially that the Union was divided into the six following sections: Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Physical Oceanography, and Volcanology, and that each of these sections has its own president and secretary, and that each may publish reports, etc.; in short, that each is an entity in itself. It was stated that Canada represented two units in the Union, its population being between five and ten millions, the maximum units being eight for population over twenty millions; and furthermore, that the Research Council had paid the first annual contribution of 5200 francs for Canada to the International Union.

Dr. Klotz amplified the remarks of the Chairman by giving an account of what had been done in the United States in connection with a similar national committee of which he had been supplied with the minutes; in connection with the National Committee there had been formed a permanent American Geophysical Union which, in co-operation with the United States National Research Council, would take part in the International Union.

Before the adjournment of the meeting, Dr. Deville and Dr. Klotz were appointed a committee to draft the necessary Constitution and By-laws for the National Committee of Canada, for subsequent submission to the Committee and then for the approval of the Research Council.

The preliminary draft of the Aims of the National Committee was prepared by the above-mentioned Committee and at a meeting held on May 19, 1921, the Statutes were amended as follows:

STATUTES

The National Committee of Canada constituted by the Advisory Council of Scientific and Industrial Research for the International Union of Geodesy and Geophysics.

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ARTICLE 1

Objects

(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems relating to the shape and physics of the earth; to initiate and organise the conduct of researches which depend on co-operation between different countries, and to provide for their scientific discussion and publication; to facilitate particular researches such as the comparison of instruments used in different countries.

(b) To promote and co-ordinate the study of the various branches of geodesy and geophysics in Canada.

(c) To formulate problems encountered in investigational work requiring solution, for presentation through the National Committee to the International Union.

(d) To seek the assistance of others not members of the National Committee in matters pertaining to any of the sections of the Union.

(e) To publish, if found desirable, the activities of the National Committee in order to further research in Canada in the various fields of the Committee of the Union.

ARTICLE 2

Membership

The membership of the National Committee shall consist of the eleven originally provided by the Research Council, and such other active investigators in the above fields who have been proposed to the National Committee, and whose election requires a two-thirds affirmative vote by ballot of the members of the National Committee. Additional members may be elected without calling a meeting of the Committee.

ARTICLE 3

Sections

The National Committee shall be divided into Sections corresponding to those of the International Union, viz: Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Physical Oceanography, and Volcanology. Each section may appoint its own Chairman and Secretary.

The members shall designate the Section, or Sections, to which they desire to belong.

ARTICLE 4

Officers

The officers of the National Committee shall be a Chairman and a Secretary to serve until the conclusion of the next General Assembly of the International Union and until their successors have been duly elected.

ARTICLE 5

Appointments

In case of absence of the Chairman at any meeting, the meeting shall appoint a temporary Chairman for such meeting.

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ARTICLE 6

Executive Committee

The Executive Committee shall consist of the Chairman and Secretary, and the Chairmen of Sections, if such have been appointed.

The Chairman and Secretary of the National Committee shall be the corresponding officers of the Executive Committee.

ARTICLE 7

Delegates

The National Committee shall nominate a delegate or delegates to the International Union of Geodesy and Geophysics at least six months before the next meeting of the General Assembly.

ARTICLE 8

Amendment

Amendments to the Statutes may be made at a meeting called for that purpose provided notice of such amendment has been sent to the Secretary at least one month before the above meeting.

The question of additional membership and the personnel of the various Sections was taken up at the meeting held on May 10, 1921. It was decided to increase the membership of the National Committee as provided for in Article 2 of the Constitution; also, in order to facilitate the work of the Committee and Sections, to appoint the Chairman and Secretary of each Section. Each new member was elected and assigned to a Section as that particular Section was under consideration, it being assumed that the action of the Committee in assigning the member to the Section would meet with his approval. The members constituting the the different Sections, also the officers, as chosen by the members present, are as follows:

Geodesy

Chairman, Dr. E. Deville, Chairman, National Committee, Ottawa.
Secretary, Noel J. Ogilvie, Superintendent of the Geodetic Survey of Canada, Ottawa.
Professor L. B. Stewart, University of Toronto, Toronto.
W. M. Tobey, Senior Geodetic Engineer, Geodetic Survey of Canada, Ottawa.

Seismology

Chairman, E. A. Hodgson, Seismologist, Dominion Observatory, Ottawa.
Secretary, F. Napier Denison, Meteorological Service, Victoria.
Dr. Otto Klotz, Director, Dominion Observatory, Ottawa.

Meteorology

Chairman, Sir Frederick Stupart, Director, Meteorological Service, Toronto.
Secretary, J. Patterson, Meteorological Service, Toronto.

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Terrestrial Magnetism and Electricity

Chairman, Dr. Otto Klotz, Director, Dominion Observatory, Ottawa.
Secretary, C. A. French, Magnetician, Dominion Observatory, Ottawa.
W. J. Stewart, Chief Hydrographer, Department of Marine and Fisheries, Ottawa.
W. E. W. Jackson, Magnetician, Meteorological Service, Toronto.

Physical Oceanography

Chairman, Dr. W. Bell Dawson, Superintendent of Tidal and Current Surveys, Department of Marine and Fisheries, Ottawa.
Secretary, W. J. Stewart, Chief Hydrographer, Department of Marine and Fisheries, Ottawa.

Volcanology

Chairman, Dr. William D. McInnes, Director of Victoria Memorial Museum, Ottawa.
Secretary, Dr. W. H. Collins, Director of the Geological Survey, Ottawa.
Professor R. W. Brock, University of British Columbia.

The membership of the National Committee of Canada of the International Union of Geodesy and Geophysics, including the eleven original members, is at present twenty-one.

The fees for Canada due to the International Union of Geodesy and Geophysics are at present charged to the appropriation of the Geodetic Survey of Canada.

In conclusion I may say that the aims and organization of all the Sections of the National Committee of Canada, namely, Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Physical Oceanography and Volcanology, are first to co-operate with other investigators in the British Empire, and to unify and co-ordinate all results with those of the United States and Mexico, so as to build up one complete whole over North America, and secondly, to co-operate as much as possible with the whole of Europe, etc., in the obtaining of uniform results and methods which can be used for scientific purposes.

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STATUTES AND BY-LAWS OF THE AMERICAN GEOPHYSICAL UNION

(As amended to May, 1923.)

PREAMBLE

The American Geophysical Union is hereby established by the National Research Council. It supersedes the "American Section of the proposed International Geophysical Union." The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The American Geophysical Union is constituted as follows:

ARTICLE 1

Objects

(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and co-ordinate researches which depend upon international co-operation, and to provide for their scientific discussion and publication; and to facilitate special researches, such as the comparison of instruments used in different countries.

(b) To promote and co-ordinate the study of the various branches of geodesy and geophysics in the United States of America and its outlying territories.

ARTICLE 2

Membership

The membership of the American Geophysical Union shall be as follows:

(a) Those who composed the membership of the "American Section of the proposed International Geophysical Union" on July 1, 1919.

(b) Those who may be appointed by the Executive Board of the National Research Council upon nominations submitted by the Executive Committee of the American Geophysical Union.

(c) The Chairman of the Division of Foreign Relations, the Chairman of the Division of Physical Sciences, the Chairman of the Division of Chemistry and Chemical Technology, the Chairman of the Division of Geology and Geography, and the Chairman of the Division of Biology and Agriculture, of the National Research Council, members *ex officio*.

(d) The American officers of the International Geodetic and Geophysical Union and of its Sections, members *ex officio*.

ARTICLE 3

Sections

The American Geophysical Union shall be divided into Sections, in accordance with the organization of the International Geodetic and Geophysical Union, as follows: (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Mag-

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netism and Electricity; (e) Oceanography; (f) Volcanology; and, in addition, (g) Geophysical Chemistry.

The members shall designate the Section, or Sections, to which they will belong. The *functions of the Sections*, in their respective fields, shall be the promotion of the objects of the American Geophysical Union.

ARTICLE 4

Officers of the American Geophysical Union

The *Officers of the American Geophysical Union* shall consist of a chairman and a vice-chairman, elected to serve for a period of two years, and not to be eligible for immediate re-election to their respective offices; and a secretary, to serve for a period of three years.

ARTICLE 5

Officers of Sections

The *Officers of the Sections* of the American Geophysical Union shall consist for each Section of a chairman, a vice-chairman, and a secretary, whose periods of office shall correspond to those of the Union. The Chairman of each Section shall have the power to appoint, with the right to vote, a representative of the Section to such meetings of the Executive Committee of the Union as he may be unable to attend.

ARTICLE 6

Executive Committee

The *Executive Committee* shall consist of the chairman, the vice-chairman, and the secretary of the American Geophysical Union, and of one representative from each of the sections of the Union, who shall be the chairman thereof or a member appointed by him; and, in addition, *ex officio*, the chairman of each of the following Divisions of the National Research Council: Foreign Relations, Physical Sciences, Chemistry and Chemical Technology, Geology and Geography, and Biology and Agriculture. Those present shall constitute a quorum. This Committee shall have charge of all administrative matters of the American Geophysical Union, and shall be the representative of the Union in its relations with the National Research Council and with the International Geodetic and Geophysical Union. The Executive Committee, in consultation with the Sections, shall nominate to the Executive Board of the National Research Council delegates, or representatives, to the meetings of the International Geodetic and Geophysical Union and of its Sections, in accordance with the regulations fixed by the International Research Council for the voting power of the United States of America.

ARTICLE 7

Annual Meetings

The American Geophysical Union and its Sections shall meet annually at such time and place as may be chosen by the Executive Committee of the Union. The officers of the Union and of the Sections shall be elected at this annual meeting.

ARTICLE 8

Special Meetings

Special Meetings of the American Geophysical Union, or of its Sections, may be called when necessary by the respective chairmen.

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ARTICLE 9

By-Laws

The American Geophysical Union is authorized to enact such by-laws as may be necessary for the performance of its functions and duties.

ARTICLE 10

Amendments

Amendments to the Statutes of the American Geophysical Union shall be subject to the approval of the National Research Council.

BY-LAWS

The fiscal year of the American Geophysical Union shall conform to the fiscal year of the National Research Council.

Standing committees on Statutes and By-Laws, on Membership, on Meetings, and on Budget, shall be appointed for the ensuing fiscal year by the Chairman-elect of the Union prior to the beginning of each year.

All committees of the American Geophysical Union shall terminate at the end of the fiscal year for which they may be appointed.

Meetings of the Union shall be called at least thirty days in advance, and those present at the meeting shall constitute a quorum.

Meetings of the Executive Committee shall be called by the Chairman, and those present shall constitute a quorum.

Final action shall not be taken by the Executive Committee on matters affecting any Section in the absence of the Chairman of such Section, or his representative.

No mail ballot shall be closed until at least thirty days after the date of issue.

After thirty days' notice has been given, amendments to the Statutes (all of which are subject to the approval of the National Research Council) may be voted on either by mail or at a regular meeting of the Union.

Amendments to the By-Laws may be proposed either by mail or at a regular meeting; when voted on by mail they require for adoption a majority vote of the members; when voted on at a regular meeting they require for adoption a three-fourths vote of the members present.

Any amendment to the Statutes or By-Laws proposed by at least five members shall be submitted for vote to the members of the Union by the Executive Committee.

A member of the American Geophysical Union may be dropped from the Union by a three-fourths vote of the members of the Executive Committee.

Statutes and By-Laws adopted by a Section shall not conflict with the provisions of the Statutes and By-Laws of the Union.

Matters pertaining to a Section or Sections, and not pertaining to the Union as a whole, shall be acted upon by the Section or Sections concerned.

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REPORT OF MEETING OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION AND ITS SECTIONS HELD AT ROME, MAY 2–10, 1922, PREPARED BY DELEGATES FROM THE UNITED STATES

GENERAL CONFERENCE OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION

WILLIAM BOWIE

The first general conference of the International Astronomical Union and of the International Geodetic and Geophysical Union, since their establishment at Brussels in July 1919, was held at Rome, Italy, May 2 to 10, 1922. The meetings of the two Unions and of their various Sections were held in the Reale Accademia dei Lincei. About three hundred delegates and guests, representing about twenty countries, attended the various meetings.

The first day was occupied by the registration of delegates and the opening of the conference, which was held at the Campodoglio, at which were present the King of Italy and other officials. On the second day there were meetings of the two Unions at which various committees were appointed to consider certain questions of administration and policy. On the last day of the conference the Unions also met to receive reports of committees and to conclude the work of the conference. From May 4 to 9, 1922, inclusive, there were held meetings of the several sections of the International Geodetic and Geophysical Union and of the Committees of the Astronomical Union.

The principal matters coming before the Union as a whole were finance and changes in the statutes and organization of the Union. There was complete harmony among the delegates as to the report of the Committee on Finance, dealing with the apportionment among the sections of the quotas of the nations adhering to the Union.

On the question of changing the statutes some decided differences of opinion arose, especially on the question of whether the designation "Section" should be changed to that of "Association" or to some other term. It was the opinion of the American delegates that the term Section does not carry as much authority nor give quite the idea of importance of the several groups of scientists coordinated into the International Geodetic and Geophysical Union. The conference decided that the matter of changing the designation of the Sections should be left to the action of the International Research Council which was to hold a meeting in July 1922.

It was decided, with very little opposition, to recommend to the

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International Research Council that the countries adhering to the Reduced Geodetic Association should be allowed to join the Section of Geodesy only, without adhering to the other Sections of the Union. It was also decided that a new Section called Section of Scientific Hydrology, should be added to the Union.

Although there were many advantages in having the two Unions meet at the same time and place it was the feeling of many delegates that the time was entirely too short to accomplish all that was desired by the Sections of the International Geodetic and Geophysical Union and by the various Committees of the International Astronomical Union. Many of the delegates were accredited to both Unions and, necessarily, two or more meetings in which they were interested were frequently held at the same time.

It was decided by the officials of the International Geodetic and Geophysical Union that they would bring before the Union the question of having a meeting in 1924, in order that, thereafter, the three-year interval would bring the meeting of the two Unions in different years. At the close of the meeting of the International Geodetic and Geophysical Union it was decided that the next meeting should be held in 1924 at Madrid, Spain. Representatives of Spain had kindly invited the Union to meet in that city.

As usual, in international scientific conferences social features played a prominent part. The most important of those at the Rome meeting were the inaugural ceremony, at the Campodoglio, mentioned in the early part of this report, the reception at the same place by the municipality of Rome, on the evening of May 4, the visit to the Palatino at the invitation of the Secretary of Antiquities and Fine Arts on the afternoon of May 8 and the visit to the Vatican and the audience with the Pope, on May 10. There were a number of special excursions during and after the meeting, especially one to a number of volcanoes after the close of the conference. At the closing session of the Union appropriate resolutions were adopted, expressing the appreciation of the delegates to those individuals and organizations who by their efforts had made the conference so successful and pleasant.

The following table shows the officers of the International Geodetic and Geophysical Union and of its Sections:

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Officers of the Union

President: Ch. Lallemand
Vice Presidents: Presidents of the Sections
Secretary General: H. G. Lyons

Officers of the Sections

Section	President	Vice President	Secretary
Geodesy	W. Bowie	R. Gautier	G. Perrier
Seismology	H. H. Turner	E. Oddone	E. Rothé
Meteorology	Napier Shaw	C. F. Marvin E. Delcambre	F. Eredia
Terrestrial Magnetism and Electricity	C. Chree	L. Palazzo	Louis A. Bauer
Oceanography	Prince of Monaco[1]	J. Parry (Tidal Commission) Odon de Buen (Atlantic Commission) G. W. Littlehales (Pacific Commission)	G. Magrini
Volcanology	A. Lacroix	H. S. Washington	A. Malladra G. Platania
Scientific Hydrology	E. B. H. Wade	A. Wallén	G. Magrini

U. S. Coast and Geodetic Survey, Washington, D. C.

REPORT OF THE SECTION OF GEODESY

WILLIAM BOWIE

As is well known, the geodesists of the world have maintained for a number of years an association called the International Geodetic Association. At its last meeting at Hamburg, Germany, in 1912, the fiftieth anniversary of the Association was celebrated. That Association had held triennial conventions for the purpose of bringing together representative geodesists from the twenty or more adhering countries.

That the International Geodetic Association and its conferences were of great benefit to the science of geodesy is indicated by the fact that practically all of the geodetic work done throughout the world since the organization of the Association has been of such a high standard that it has not had to be duplicated. These beneficial results have been largely due to the personal contact of the geodesists with each other at the triennial conventions and to the efforts of committees and rapporteurs dealing with the various branches of geodesy, and of the officials of the association.

[1] The President died soon after the meeting.

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The Section of Geodesy of the International Geodetic and Geophysical Union, which was created at Brussels in 1919, was designed to take the place of the old International Geodetic Association which had been greatly reduced as a result of the war. The old Association had been perpetuated in 1917 by seven neutral countries of which the United States was one; the others were Norway, Sweden, Denmark, Holland, Switzerland and Spain. After the United States entered the war, the Association was composed only of the other six countries mentioned. Too much credit cannot be given to those countries for preventing a break in international co-operation in geodetic affairs during the war. Especial credit is due to the president of the reduced Association, Dr. Raoul Gautier, and the late Dr. H. G. van de Sande Bakhuyzen, the Secretary.

As a result of correspondence of the President and Secretary of the Section of Geodesy with the officials of the reduced Geodetic Association, each one of the countries forming that Association had representation at the Rome meeting in May, 1922.

The Section of Geodesy held almost continuous sessions from the third day of the conference to and including the next to the last day. The first two days and the last day of the conference were devoted to the opening exercises and the meetings of the International Astronomical Union and the International Geodetic and Geophysical Union.

An Agenda had been prepared for the meeting of the Section of Geodesy which, with much explanatory material showing what had been done by the officials of the Section since the organization of the Section at Brussels, was furnished in printed form to the delegates at Rome. The Agenda was very strictly adhered to in the proceedings of the Section, and all that had been projected was accomplished, although there was much crowding of events owing to the limited time available.

At the first session of the Section, a number of committees were appointed, which dealt with questions involving cooperation of geodesists in two or more countries. There was also provided a committee, which should meet with a committee of the International Astronomical Union, to consider the question of the international variation of latitude work. Another committee was appointed to deal with the finances of the Section.

The meetings of the Section of Geodesy were well attended with from 25 to 50 persons present. Committee meetings which, in some cases, had to be held during the sessions, cut down the attendance at various times; besides, some of the geodesists were also representa-

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tives of their countries to the International Astronomical Union and to other sections of the Geodetic and Geophysical Union and, necessarily, they were not able to devote all of their time to the Geodetic Section.

The statutes and by-laws of the International Geodetic and Geophysical Union were adopted for the guidance of the Section of Geodesy.

One of the most serious questions which came before the Section was the character of its organization but, after much thought and unselfish effort on the part of a committee appointed on the statutes and organization, a plan was drawn up which was submitted to the Section and adopted without modification. This plan provides that there shall be a president, vice-president and secretary who shall form the Bureau of the Section. These officers together with four others elected by the Section at a general conference will constitute an Executive Committee to carry out the will of the Section, as expressed in its acts at the general conferences, and also to carry out the will of the Permanent Commission.

It was provided that there should be a Permanent Commission of the Section of Geodesy, which should be composed of a single representative of each of the states adhering to the Section. This Commission would have as its principal function to act for the Section on legislative matters which might appear to be necessary during the interval between two general conferences.

The joint committee of the Section of Geodesy and of the International Astronomical Union, on the variation of latitude work, reported that unanimous agreement had been reached, that the latitude work should be conducted by the Section of Geodesy but that there should be a joint committee of the Section of Geodesy and of the Astronomical Union, to consider the various scientific phases of the subject. It was also provided that the Astronomical Union should make contribution towards the reduction, discussion and publication of the results.

The writer of this report made the statement at one of the sessions of the Section of Geodesy that he was authorized to propose that, if the property of the reduced Geodetic Association, at the two variation of latitude stations in the United States, Ukiah, California, and Gaithersburg, Maryland, were transferred to the U. S. Coast and Geodetic Survey, every effort would be made to secure the authority of Congress for the Coast and Geodetic Survey to continue the observations in this country without expense to any international body, provided that the stations in Japan and Italy should be main-

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tained without international expense by those two countries. The representatives of Japan and Italy agreed to this proposition provided, of course, their countries would confirm their action. Since the Rome meeting the Director of the U. S. Coast and Geodetic Survey has been in communication with the Secretary of the Section of Geodesy, making efforts to put into effect the plan proposed at Rome.

At the last session of the Section of Geodesy, reports were received from the various committees which had been appointed at the beginning of the conference, and such action was taken on the reports as seemed desirable. It is not necessary to refer to the Committee reports, except in so far as has already been done in the early part of this statement for there will be given a complete report of the proceedings at Rome in the *Comptes-Rendus*, now being prepared by the Secretary.

The Section of Geodesy elected as its vice president Raoul Gautier who since the death of General Bassot of France, in January, 1917, has been president of the reduced Geodetic Association. The four members elected to the Executive Committee are H. J. Heuvelink, G. P. Lenox-Conyngham, Paul Stroobant, N. Vacchelli.

William Bowie of the United States will continue as President of the International Section and G. Perrier of France will continue as Secretary for another term.

It was provided that there should not be any Central Bureau, such as had existed in the old International Geodetic Association. To replace the Central Bureau, provision was made for rapporteurs for the several branches of geodesy. The rapporteur for a subject would have as his duties the collection of information from the geodesists of the world and the furnishing of information and advice to such as might desire it from the officials of the Section, and the making of a report at the general conventions on the status of the subject assigned him and the progress which has been made since the preceding conference.

The following rapporteurs were appointed at the Rome meeting: Bases and Triangulation, G. Perrier; Precise Leveling, Ch. Lallemand; Geodetic Astronomy (latitude, longitude, azimuth), to be designated by Ordnance Survey; Deviation of Vertical, H. DeGraaff Hunter; Intensity of Gravity, E. Soler; Isostasy, W. Bowie; Projections, H. Roussilhe; Earth Tides, H. G. Gale; Stability of the Earth as a Timepiece, E. W. Brown.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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REPORT OF THE SECTION OF SEISMOLOGY

HARRY FIELDING REID

The meeting of the Union took place in Rome, May 2-10, 1922, at the headquarters of the Reale Academia dei Lincei.

The Section of Seismology, which was not organized in Brussels in 1919, on account of possible complications with the International Seismological Association, was organized on May 4. Professor H. H. Turner, of Oxford, England, was elected President; Signor Emilio Oddone, of Rome, Italy, Vice-President; and M. Rothe, of Strasbourg, France, Secretary and Director of the Central Bureau, which it was decided to maintain at Strasbourg.

The section is to receive 27,000 francs annually from the Union, a sum far inferior to the income of the former International Seismological Association (about 51,000 marks). Its activities will therefore be much restricted. To continue the cataloguing of important earthquakes recorded by seismographs, 10,000 francs annually were voted to Professor Turner, who will have to supplement this sum (by probably an equal amount) from other sources. The remainder of the income, 17,000 francs, was voted to the expenses of the Central Bureau: they will be used to publish the proceedings of the meetings, to disseminate seismological information by wireless, to carry on the general work of collaboration of the Central Bureau, and, if possible, to publish some memoirs; but the activities of the Section will necessarily be more restricted than were those of the old Association.

Several committees were appointed: (1) to work out a practical system of rapid transmission of seismological information (2) to consider the transmission of earth waves due to explosions (3) to consider a means of expressing the usual scales of earthquake intensities in dynamic units (4) to study the cause of microseisms (5) to study the depths of earthquake foci.

Three seismological papers were read and discussed. M. Somville (Belgium) gave a simplified method of determining the constants of a Galitzin seismograph, Signor Lo Surdo (Italy) explained an easy method of determining experimentally the intensity of earthquake vibrations in dynamical units, and of correlating this intensity with the Rossi-Forel, the Mercalli, or any other similar scale; and Mr. Reid (United States) showed that the friction of seismographs registering mechanically could be taken into account satisfactorily more accurately and more simply than by Galitzin's theory.

An interesting excursion was made by the Section to Rocca di Papa, the principal Italian seismological observatory. A luncheon was

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given by the Mayor of the town, and Professor Agammenone, in charge of the observatory, received us most cordially and explained the instruments and the work he is carrying on.

Johns Hopkins University,
Baltimore, Maryland.

REPORT ON THE DISSOLUTION MEETING OF THE INTERNATIONAL SEISMOLOGICAL ASSOCIATION, STRASBOURG, APRIL 24-25, 1922

HARRY FIELDING REID

The delegates met at the Institute de Physique du Globe, Strasbourg, April 24-25, 1922. The following allied nations were represented by delegates: Belgium, Brazil, Canada, France, Great Britain, Japan, Norway, Portugal, Spain, Switzerland, United States.

Dr. Hecker (Germany), former director of the Central Bureau of the Association, and Professor de Kovesligethy (Hungary), former secretary were present. Several other states of Central Europe were represented by proxy.

On account of the death of Prince Galitzin, the president of the Association, and the illness of Professor Lecointe, the vice-president, Sir Arthur Schuster, a former president, was elected to preside.

It was decided that the International Seismological Association came to an end on March 31, 1916, that being the end of the period determined by the original convention. It seems that some States have not paid their quota to that date, whereas others have paid their quota for some succeeding years. It was decided to ask all States in arrears to March 31, 1916, to make up their arrears; and to return to all States which have paid quota beyond that date the sums so paid. If the member States agree to this plan and act accordingly there will remain in the treasury of the Association about 18,400 francs. (It is not certain that all arrears can be collected.) It was decided to pay to the former secretary, Professor de Kovesligethy the sum of 5000 francs for the very considerable work devolving on him in closing up the affairs of the Association, and to use the remainder for printing and distributing the proceedings of the Dissolution Meeting, and in meeting other small expenses incident to the dissolution.

It was decided to transfer to the Seismological Section of the International Geodetic and Geophysical Union, the library and scientific documents, and other properties of the Association. The "other properties" are unimportant.

The decisions of the meeting were adopted unanimously. In order

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to make these decisions effective, it is necessary that the member States ratify them. I think them eminently fair and practical, and I strongly hope that our State Department will ratify them. They offer a simple solution of what might have been a difficult matter. Our country has paid its quota to the Association only to March 31, 1915, and therefore according to its undertaking when it joined the Association, and in accordance with the action of the Dissolution Meeting, it still owes one year's quota, April 1, 1915 to March 31, 1916. The amount is 4000 francs, which, at the present rate of exchange is but little over three hundred dollars. Our annual quota before the war was 3200 marks, or about $800.

Johns Hopkins University,
Baltimore, Maryland.

REPORT OF THE SECTION OF METEOROLOGY

HERBERT H. KIMBALL

Meetings were held daily, except Sunday, from May 4 to 9, inclusive, and in addition a joint meeting with Section (D), Terrestrial Magnetism and Electricity, was held on May 5. Sir Napier Shaw of England presided at all the meetings. In the absence of Professor Marvin, the Secretary, Dr. Kimball, the delegate from the United States, was asked to serve as Secretary pro tem; and Professors Platania and Eredia, delegates from Italy, were designated Assistant Secretaries.

In all, thirty-three delegates were in attendance, representing most of the allied nations, and a few that were neutral, during the world war.

The Section particularly concerned itself with two subjects: (1) its relations with the International Meteorological Committee, and the International Conference of Directors of Meteorological and Magnetic Institutions, and (2) plans for international cooperation on certain research problems.

With reference to (1) it was agreed that all questions of a routine or an administrative character should be referred for consideration to the International Meteorological Committee, the Section confining its activities to scientific problems the solution of which calls for international cooperation. Furthermore, the International Conference of Directors of Meteorological and Magnetic Institutions, which is to meet in Holland in 1923, was asked to consider if there is a duplication of work in its functions and those of the Union.

With reference to (2) resolutions were adopted providing for certain researches, the procedure for the carrying out of which will be

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outlined later by the Bureau of the Section. These researches include the following:

(1) The determination of the quantities of hydrogen in the atmosphere in different localities and at different heights.

(2) The exploration of the upper atmosphere by means of sounding balloons in regions which are of especial importance from the point of view of the general circulation of the atmosphere, and which have not at the present time an effective meteorological organization for carrying on work of this kind.

(3) The examination of the dust in the atmosphere in different countries.

(4) A report on our knowledge of the radiation from the sun, the soil, the sea, and the air, from the point of view of the general circulation of the atmosphere.

(5) A report from the several countries affiliated with the Union on the methods they employ in weather forecasting.

(6) A study of the details of convection in the atmosphere.

(7) Commendation of the work on solar radiation carried on by the Astronomical Observatory of Naples, and by the Astrophysical Observatory of the Smithsonian Institution of Washington.

The budget of the section was approved as follows:

General expenses	5,000 francs
Exploration of the air by sounding balloons	20,000 francs
Exploration of the stratosphere by pilot balloons	5,000 francs
Examination of the dust of the atmosphere	2,500 francs
Total	32,500 francs
Allotment	32,542 francs

The Bureau of the Section is constituted as follows:

President,	Sir Napier Shaw,	England.
Vice President,	Professor C. F. Marvin,	United States.
Vice President,	Colonel Delcambre,	France.
Secretary,	Professor F. Eredia,	Italy.

The Executive Committee consists of the Bureau, and the following:

Dr. G. C. Simpson,	England.
M. Alex Wallen,	Sweden.
Professor F. Gamba,	Italy.

U. S. Weather Bureau,
Washington, D. C.

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REPORT OF THE SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY[1]

LOUIS A. BAUER

A well-attended meeting of the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union was held at Rome from May 4–9, 1922. During the seven sessions, twelve different countries were represented by thirty-three delegates and guests, viz:

J. M. Baldwin, G. F. Dodwell, E. F. Pigot (Australia); J. Jaumotte (Belgium); H. Morize (Brazil); J. Bosler, H. Deslandres, E. Delcambre, E. Mathias, Ch. Maurain (France); C. Chree, A. L. Cortie, W. C. Parkinson, Arthur Schuster, Napier Shaw, G. C. Simpson (Great Britain); A. Alessio, F. Eredia, L. Palazzo, D. Pacini, G. Platania, A. Pochettino, G. B. Rizzo, C. Somigliana (Italy); K. Nakamura (Japan); J. Krassowski (Poland); J. Galbis, L. Rodés (Spain); D. Stenquist, A. Wallen (Sweden); L. A. Bauer, G. W. Littlehales (United States); E. Deville (Canada).

Professor Tanakadate, who was unable to be present at Rome, had requested to be relieved of the presidency of the Section, because of his inability to attend to the duties. The resignation was regretfully accepted and Dr. Charles Chree, who as vice-president had presided at all sessions, was elected, at the closing session on May 9, president, and Professor Luigi Palazzo, vice-president; both of these officers, according to the statutes, serve for two terms. The secretary and director of the Central Bureau, Dr. Louis A. Bauer, continues in office until the next meeting, which will be at Madrid, Spain, about September 1924. Directors J. Jaumotte (Belgium) and Ch. Maurain (France), and Professor A. Tanakadate (Japan), in addition to the three officers of the Section, were constituted the Executive Committee. It was agreed that administrative matters should be left to the Bureau, consisting of the officers of the Section.

Since the meeting at Brussels in July 1919, when the International Section of Terrestrial Magnetism and Electricity was established, nearly three years have elapsed. While the organization of the work of the Section, because of the post-war conditions, could not proceed as rapidly as it was hoped, nevertheless definite progress has been made regarding which the Agenda (Ordre du Jour) for the present

[1] The full report has appeared in a volume published by the International Section and is entitled "Transactions, Section of Terrestrial Magnetism and Electricity, Rome, 1922"; it is designated as "Bulletin No. 3." A general report, published in the September 1922 issue of *Terrestrial Magnetism and Electricity*, was reprinted as "Bulletin No. 2," and a copy was sent to each member of the American Geophysical Union.

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meeting were at least one indication.[2] Perhaps for the first time we have had presented in so concrete a form the salient questions, both practical and theoretical, pertaining to the magnetic and electric states of our Earth and its atmosphere. It was not to be expected, nor indeed, was it desirable, that definite decisions on all the questions should be reached at that meeting. However, it must be a source of gratification that by the united action of the National Committees the crucial questions and problems have received a definite formulation.

Reports were presented showing the status of magnetic and electric work in the various countries represented, and containing the opinions of National Committees, leading organizations, and investigators on items of the Agenda. There were, furthermore, reports from committees constituted at the Brussels meetings, as also reports and letters expressing the views of some, whose countries either were not officially represented at Rome (Greece, New Zealand), or did not yet belong to the International Geodetic and Geophysical Union. Among the latter there were letters from E. van Everdingen (Holland); G. Reinius, D. Stenquist, and V. Carlheim-Gyllensköld (Sweden); C. Störmer (Norway); G. Melander (Finland); and C. Ryder (Denmark).

On the basis of all information on hand and the ensuing discussions on items of the Agenda, twenty Resolutions[3] were passed. The Executive Committee was empowered to formulate more definite recommendations on some of the mooted questions of procedure, especially at magnetic observatories, as soon as further information has been received by the secretary from all service and observatories engaged in magnetic or electric work, in response to a questionnaire sent out.

Five committees were appointed:[4] (1) Committee on Magnetic Surveys and International Comparisons of Instruments; (2) Committee on Observational Work in Atmospheric Electricity to report on Objects, Instruments, and Methods; (3) Committee on Measures of Magnetic Characterization of Days; (4) Committee on Best Methods, Instruments and Compilations for Polar Light Observations; and (5) Committee to Consider and Report on Best Methods and Instruments for Earth-Current Observations. The provisional organization of these committees was undertaken. The Executive Committee was

[2] See *Terr. Mag.*, vol. 26, pp. 151–152, 1921 for English text; the French text will be found in the reprinted general report (Bulletin No. 2).

[3] See reprinted general report (Bulletin No. 2), or "Transactions" (Bulletin No. 3, pp. 174–177).

[4] The representatives of the American Geophysical Union on the international committees are: (1) Louis A. Bauer, chairman, and N. H. Heck; (2) W. F. G. Swann; (3) R. L. Faris; (4) J. A. Fleming; (5) S. J. Mauchly, secretary.

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empowered to add to the membership of committees, as additional countries join the Union, and to form any additional committees deemed necessary to put into effect the Resolutions. Provision has also been made for consideration of questions concerning the relationships between solar and the Earth's magnetic and electric phenomena in the following manner: (1) A committee on solar radiation, under the chairmanship of Dr. George E. Hale, of which Dr. Bauer is a member, was formed by the International Astronomical Union; (2) The International Research Council at its Brussels meeting in July 1922 has decided to assist in initiating studies of the correlations between solar and terrestrial phenomena, this being a subject of the kind in which several unions would be interested.

The balance, 30,892 francs, of the accumulated funds in hand, arising from the contributions, 1919–1922, of the adhering countries at the rate of 400 francs per contributing unit, was made available to the International Section. This is in addition to the sum of about 1,500 francs which had been supplied in 1921 for incidental expenses. There will, furthermore, be available during the period of 1922–1924, from the contributions of adhering countries, annually an amount at the rate of 320 francs per contributing unit. It is estimated that the annual amount from this source will be about 22,000 francs. Hence the International Section will have available for its various purposes during the period 1922–1924, in all about 75,000 francs,[5] which is subject to increase as additional countries join the International Geodetic and Geophysical Union. With the aid of the funds thus available it is hoped that matters of international concern and benefit may be energetically pursued, as, for example, frequent intercomparisons of magnetic standards, the chief expense of which during the past sixteen years has been borne by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The Secretary and Prof. E. Mathias, as alternate, were made members of the Finance Committee of the Union.

The Executive Committee was authorized to incur the necessary expense for the publication, in the most suitable form, of the minutes and proceedings of the Rome meeting and of the various reports received, as well as for the issue of any additional publications which may be found desirable and which the available funds may permit. It is estimated that the volume of proceedings will approximate 200 octavo pages, and that it may be distributed in 1923.[5] By means of bulletins, issued from time to time, it is hoped that prompt information may be given regarding matters of international interest, progress

[5] Approximately, according to present rate of exchange, about 4,000 United States dollars.

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on mooted questions, action taken and recommendations by the Executive Committee, and other committees of the Section, and National Committees, latest values of the magnetic and electric elements at observatories, and so forth.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

REPORT OF THE SECTION OF PHYSICAL OCEANOGRAPHY[1]

G. W. LITTLEHALES

At the first assembly of the Section, which took place on Wednesday, May 3, 1922, confirmation was given to the recommendations of the Executive Committee for the appointment of three commissions to be called, respectively, the Commission of the Atlantic, the Commission of the Pacific, and the Commission of the Mediterranean.

The proposal of the Executive Committee that, in addition to the president or chairman of the Tidal Commission, the presidents or chairmen of these three commissions should be vice-presidents of the Section was adopted.

Your delegate was elected Vice-President of the Section and President of the Commission of the Pacific, and was continued in membership in the Commission of the Atlantic and its sub-commission and also in the Tidal Commission. Steps have been taken to organize the Commission of the Pacific in harmony with the Committee on Pacific Investigations of the Division of Foreign Relations of the American National Research Council.

The Commission of the Mediterranean was continued as constituted in November, 1919.

Indorsement was given to the proposal of Senator Volterra, for the publication in the Bulletin of the Section the *Comptes Rendus* of transactions in physical oceanography throughout the world.

The proposal of Professor Magrini, for the formation of a new section in the International Union of Geodesy and Geophysics to be called the Section of Continental Hydrography was referred to a special committee of which the American delegate to the Section of Physical Oceanography was a member. The proposal was opposed under instructions from the American delegation. This opposition

[1] A detailed report of the proceedings of the International Section of Physical Oceanography at its meeting in Rome May 2–10, 1922, is soon to be published by the Secretary of this Section, in connection with the reports of the other Sections of the International Union of Geodesy and Geophysics and with the report of the proceedings of the Union itself. Accordingly the present statement touches only upon such transactions as are entitled to anticipatory mention.

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occasioned the modification of the proposal of Professor Magrini into a new proposal for the creation of a Section of Scientific Hydrology, which was adopted by the Committee of the Union appointed to consider and report upon the original proposal.

The committee appointed to prepare an International Glossary of Nomenclature and Terms used in Hydrography and Oceanography reported an advanced stage of progress.

A new committee was appointed to examine into existing international conventions which might aid researches in physical oceanography.

The International Hydrographic Bureau was brought into connection with the International Section of Physical Oceanography by the election, as a Vice-President of the Section and Chairman of the Tidal Commission, of Sir John Parry, President of the Directing Committee of the International Hydrographic Bureau. This proceeding followed the resignation of Professor Lamb as Vice-President of the Section and Chairman of the Tidal Commission.

The Tidal Commission reported in favor of introducing, into the title-note concerning tides on nautical charts, a table of harmonic constants for the computation of the time of tide instead of the usual statement of the Establishment of the Port or High Water at Full and Change, especially in these regions where declinational tides are predominant.

At the final meeting of the Section on May 10, in connection with the passage of the budget for the ensuing fiscal year, provision was enacted for the annual expenditure of 5,000 francs in each of the ensuing five years for the preparation and printing of the International Manual of Oceanography.

U. S. Hydrographic Office,
Washington, D. C.

REPORT OF THE SECTION OF VOLCANOLOGY

H. S. Washington

I have the honor to report as follows on the meeting of the Section of Volcanology held at Rome, Italy, May 2–10, 1922. It will be pertinent to state that I have not yet received any copy of the minutes of the Proceedings made by the Second Secretary, Prof. Gaetano Platania, of Catania. I understand that he met with a somewhat serious accident, which has evidently delayed him. I must consequently rely on my memory and on some scanty notes made by me. The present report must, therefore, be considered as subject to correction in the future.

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The first meeting of the Section of Volcanology was held at the rooms of the Accademia dei Lincei, in the Corsini Palace, at Rome, on May 4. Those present were: Messrs. Lacroix (France); Malladra, Millosevich, Nasini, Novarese, Oddone, Gaetano Platania, and Somigliana (Italy); Iwawate (Japan); and Washington (United States). Prof. Lacroix was elected Chairman of the Section for a term of three years, and Dr. Washington was elected Vice-Chairman for a like period. Dr. Malladra was elected First Secretary to fill out two years more of his term, and Prof. Gaetano Platania was elected Second Secretary. In the absence of Prof. Malladra after the first day, Prof. Platania acted as Secretary during the whole meeting.

A general discussion of the agenda which had been proposed for consideration took place. These agenda were:

1. International co-operation in the sending out of news and information regarding new eruptions.

2. International co-operation on the obtaining of data regarding submarine eruptions and earthquakes, and the examination of ships' log books for records of them.

3. The subject of deep borings at volcanoes. During the discussion of this topic an interesting account of the Larderello Works in the development of power from subterranean heat and steam was given by Prof. Nasini and one of the engineers of the company.

4. International Catalogue of Volcanoes.

5. Study of thermal gradients.

Other matters discussed were: The publication of a Bulletin of Volcanology; what should be understood by the term "active volcano"; an international bibliography of the active volcanoes of each country; the establishment of a central volcanological library. Further consideration of these matters was laid over until the next meeting.

The next and last meeting of the Section took place on May 9, the same persons being present, except Dr. Malladra. Discussion of the topics mentioned above took place; it was finally decided that the formulation of definite proposals and decisions be left to a Committee composed of Messrs. Lacroix, Malladra, and Washington, who were to meet later at Vesuvius. Announcement was made by the chairman that the annual income of the Section would be about 20,000 francs, derived from about 70 units of the International Geodetic and Geophysical Union, each unit being 260 francs. After the usual votes of thanks the meeting then adjourned, until the next meeting to be held in Madrid, Spain, in 1924.

After the meeting an excursion was made to the active volcanoes of Italy by Prof. and Mme. Lacroix, Prof. and Signora Gaetano Platania, Prof. Oddone, Prof. Iwawate, Dr. Washington, and several

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others. The trip lasted from May 12 to 22 and included an excursion around Etna by rail and motor car, the ascent of the volcano and the spending of the night at the top. The Aeolian Islands were visited, by the courtesy of the Ministry of Marine, who placed a torpedo boat at our disposal. A night was spent on Lipari, the volcano of Vulcano was visited, and a night circuit gave a splendid view of the activity of Stromboli, and the ruins of Messina were seen. On the return the crater of Vesuvius and the Observatory were visited by several members of the party.

Messrs. Lacroix and Washington met Prof. Malladra at the Observatory of Vesuvius on May 21, and held the Committee meeting; at this meeting Prof. H. F. Reid was also present by invitation. It was agreed that:

1. The Central Bureau of the Section of Volcanology should be at the Vesuvius Observatory, with an office in Naples, to be in charge of Prof. Malladra, as First Secretary; a subsidiary bureau to be at Catania, under the charge of Prof. Gaetano Platania.

2. It was recommended that, if it can be arranged, a Bulletin des Publications Volcanologiques be established, devoted especially to the recording of volcanic eruptions and related occurrences, including hot springs, mofetti, volcanic earthquakes, the petrology and mineralogy of volcanoes, etc. It was understood that by the term "active volcanoes" those in eruption in Quaternary and Recent times be meant.

3. The publication of an International Catalogue of Active Volcanoes was recommended. It was suggested that a committee from the volcanologists of each country should take charge of the cataloging of the volcanoes of its own territory, as well as of the bibliography, as suggested in the next topic. The details of what is to be included in the catalogue were discussed, and it was agreed that each member of the present committee should make some trials as to the best procedure.

4. The publication of a Bibliography of Volcanoes was recommended, a committee from each country to deal with its own volcanoes. To determine the best form, etc., Prof. Malladra undertook to prepare a bibliography of Vesuvius, and the other two members also agreed to undertake bibliographies of some special volcanoes, such as those of Reunion or Pelee by Lacroix, and those of Hawaii by Washington.

5. It was recommended that suggestions be made to the marine authorities of the various countries as to the advisability and scientific value of issuing instructions or requests to naval and merchant marine officers and to cable companies to report on the occurrence of submarine eruptions, volcanic eruptions in little-visited islands and coastal districts, and such phenomena. It was also recommended that attempts

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be made to collate the log books of the various national navies and merchant marines for such data, if possible by some official. All such data should be reported to the central bureau at Naples.

6. The international communication of news of volcanic eruptions and the construction of a code for this purpose was discussed, but no definite action was taken.

7. It was recommended that central volcanological libraries be established at the Vesuvius Observatory, at the Geodynamic Observatory at Catania, and at the Volcano Observatory at Kilauea. To these, authors are requested to send copies of all their publications (past, present, and to come).

The meeting then adjourned.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

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STATUS OF PROBLEMS IN GEOPHYSICS

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RECENT PROGRESS IN GEODESY

JOHN F. HAYFORD

Let us consider the present status and scope of geodesy and look at its problems with a view to making the best progress possible in the near future. The recent past to be brought under review should not be limited to a single year, but to a few years. Similarly our attempt to look into the future should not be limited to the one year until we meet here again.

In recent time there has been a continually increasing application of the results of geodetic surveys to the control of other less accurate surveying and to mapping. There has been a steady improvement in instruments and methods in spite of the fact that these were already very highly developed. Geodesy is once more internationally organized. The available store of fundamental data of geodesy is being increased rapidly. In North America the extension of the area over which there is continuous triangulation all reduced to one datum has been, and is now, very rapid. Geodesy is developing many contacts with other fields of science, by discussion and by action. The discussions of isostasy have been given new life by the realization on the part of many men that isostasy brings new tests to their hypotheses in other fields of thought than geodesy and that their observations in other fields shed light upon the probable mechanism of isostatic readjustment.

This summary statement gives a general view. Let us now consider the separate items of the statement with more detail in order that we may see the matters more clearly, though in doing so we lose some of the better perspective of the compact summary.

With each passing year the statistics of routine operations show that the accurately determined elevations, lengths, directions, and positions given by geodetic surveys, are being used more and more extensively for the control of other surveys. This is the practical application of geodesy. Geodetically determined elevations, lengths, directions, and positions are used to a steadily increasing extent in the control of topographic surveys, which culminate in topographic maps. Recently, also, there has been a strong tendency to use geodetic control to an increasing extent for city surveys which culminate in cadastral surveys and in engineering estimates of proposed projects as well as in maps. Extensive practical applications of the results of any science tend greatly to bring a strong financial support to that science which in turn tends to invigorate the abstract, apparently non-practical, part of the science. That has happened in North America in the past few years.

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Geodesy is an old well-cultivated field of science. The instruments and methods of geodesy were developed to a very high degree of perfection before the year 1900. Yet in the decade which is just past, there has been a steady improvement in instruments and methods. Much of this improvement has been intended primarily to decrease the cost and to increase the speed of the observations; as, for example, the improvements in signal lights used on triangulation, in the use of invar tapes in base measurement, improvements in the details in precise leveling, and the introduction of apparatus to record wireless time-signals in observations of gravity and in longitude determinations. Such improvements contribute strongly to an ultimate increase in the accuracy of the final conclusions of geodesy. By merely increasing the *number* of deflections of the vertical and of gravity determinations of a given degree of accuracy, the accuracy and reliability of the conclusions reached are much increased. With increase in the amount of precise leveling there goes normally an increase in the number of closed circuits and a decrease in their size, and this in turn leads to a considerable increase in accuracy of the final results even though there is no change in accuracy in the observing on the separate lines of the net. The application of wireless signals to longitude determinations has made it possible to secure determinations of the highest degree of accuracy in regions, such as the greater part of Alaska for example, in which, formerly, one was forced to use the crude methods of transportation of chronometers or even of moon-culminations.

The crying demand that geodesy furnish a reasonably accurate and reliable method and instrument for determining gravity at sea has apparently produced no progress in the past year. This is probably the greatest opportunity now open for an epoch-making step in geodesy.

With the past year, the International Geodetic and Geophysical Union has become a going concern and its Section of Geodesy, which met for the first time in May 1922, focuses the thoughts of at least eighteen countries so effectively as to make it a worthy successor of the old International Geodetic Association. Once more, after a lapse of a decade, geodesy has the incalculable benefits of international co-operation.

The rapid increase in the United States in the fundamental observational data of geodesy, gravity determinations and observed deflections of the vertical, was brought before this same audience one year ago in a brief review of the statement then about to be taken by Dr. William Bowie to the meeting of the International Geodetic and Geophysical Union. Similar recent rapid progress has been made in Canada. My impression is that there are now available in North America new

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geodetic data in the form of available gravity determinations and deflections of the vertical equivalent to at least one-half of all of such data as used in the latest comprehensive geodetic discussions. It seems clear that in the near future a new comprehensive discussion would be opportune.

The most important recent development in geodesy has been the great increase in North America of the area over which there is continuous triangulation all reduced to one datum. That area in the "Supplementary investigation in 1909 of the figure of the earth and isostasy" extended, in 1909, to the four corners of the United States. But within the extreme limits mentioned, there were many large continuous blank regions which have since been supplied with triangulation. Since that time the larger of these blank regions have been greatly reduced in size by new triangulation extending through them. The most notable new pieces of triangulation, from this point of view, have been (1) a new arc of triangulation and traverse lines which is, in effect, continuous from the southern Atlantic Coast westward through Texas to a connection with the old triangulation in southern California; (2) a new triangulation in the vicinity of the 104th meridian from Pecos, Texas, to the Canadian border in North Dakota and (3) an oblique triangulation northwestward from Utah to Oregon with a branch southwestward to the vicinity of Mt. Shasta in California. Before 1900 any one of these three would certainly have been heralded to the world by a special publication and individually recognized as a worthy contribution to progress. Now, in the midst of the much more rapid advance of geodetic operations, they have attracted little attention. But of even more importance than this filling in of the gaps in the already occupied area, are extensions of that area of continuous triangulation down to latitude 17° in Mexico by the government of that country, to the northeast into Canada in the provinces of Ontario and Quebec, and the great extension to the northwest through Canada and Alaska which it is expected will become continuous from the United States to Skagway, Alaska, in the present year, 1923. In due time, in the near future, that extension may reasonably be expected to go far to the northward and westward, to the mouth of the Mackenzie River in Canada and far into the main portion of Alaska. To appreciate the great increase in the accuracy of the determination of the figure and size of the earth which is gained by such extensions of continuous triangulation on one datum, one must realize that said accuracy increases much more rapidly than the linear dimensions of the area. I estimate that in those cases in which the extension is both to new latitudes and new longitudes the accuracy varies at least as much as the cube of the linear dimensions of the

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area. It appears, therefore, that North America, through the cordial co-operation of the United States, Canada, and Mexico, will certainly, for a whole generation yet to come, have a stronger hold on geodesy, a better determination of the figure and size of the earth, and a better grip on the closely related problems than Europe and its connected continents can hope to have.

On the other hand, in Europe, together with the two continents with which it is connected by land, Africa and Asia, there is the ultimate possibility of a much larger continuous net of triangulation on one datum than can be secured on the western hemisphere. One of the auspicious signs of new progress in geodesy is the fact that at the 1922 meeting of the Section of Geodesy of the International Geodetic and Geophysical Union resolutions were passed which contemplate the development of great areas of triangulation reduced to one geodetic datum, regardless of international boundaries.

In the past decade, geodesy has developed many contacts with other fields of science. The following list of illustrations of the multiplicity and importance of these contacts is intended to make the preceding statement more concrete, though it is not intended to be exhaustive. Bowie, whose field is geodesy, has found himself forced, in recent discussions, to deal largely with geologic and physiographic aspects of the mechanics of isostasy. Barrell, a geologist, wrote the most extensive and vigorous discussion of isostasy which has appeared in the decade. Lawson, a geologist, has contributed to the understanding of the mechanics of motion in the earth's crust, especially in the form of overthrusts. Such an understanding is now evidently equally desirable to geodesy and geology since it has become clear that isostatic readjustment necessarily involves large horizontal transfers of material. Washington has shown that the densities of the rock in various portions of the earth's surface as computed from their chemical constitution are in general accord with their relative densities as inferred from the doctrine of isostasy. Nansen, in his recent book on "The Strandflat and Isostasy," finds in isostasy the solution of a great physiographic problem. The re-triangulation now in progress in California is an application of geodetic methods of thought and of observation to seismology and to studies of slow deformations of the earth's crust whether accompanied by earthquakes or not. The recent measurement of a very long base in California and its transfer to nearby mountain peaks was a loan of geodetic methods and apparatus to a physicist who is bent on a redetermination of the velocity of light. I understand that the loan has resulted in a raising of the attainable limit of accuracy of precise base measurement. All these matters are indicative of much more numerous and more intimate contacts than ever before

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between geodesy on the one hand and geology, geophysics, geochemistry, physiography, and seismology on the other hand. The geodesist no longer works in a field surrounded by a high wall; the wall is disappearing. He finds at many points that the limits of his proper field are so indefinite that he cannot be sure whether he is outside or inside. He finds the workers in adjacent fields coming in to work and talk with him and enticing him out to work and talk with them to a far greater extent than in any earlier decade.

The discussions of isostasy have been given new life by these new contacts, by the new keenness of realization of mutual interests in overlapping fields of thought.

Having in mind that experience indicates that to make the maximum progress in a given field of thought it is desirable to keep in good contact with adjacent fields and even make excursions into them, to keep all factors entering into a problem continuously in mind, and that it is also important to conquer the key problems first, I am led to make the following suggestions:

In the near future, possibly without waiting for a new determination of the figure and size of the earth, the accumulated geodetic data of North America, old and new, in the two forms (1) deflections of the vertical and (2) anomalies of gravity, on a uniform geodetic datum in each of the two cases, should be published, together with a comprehensive discussion by the geodesists in such form as will enable those in other fields of thought to continue the discussion to good advantage from their respective points of view. It is taken for granted that the data will be published both without and with corrections for topography and isostatic compensation computed on a uniform basis.

In the geodesist's discussions as published, especial attention should be given to the character and the rapidity of change of the deflections of the vertical, and of gravity anomalies, as one progresses horizontally from station to station. Is the isostatic compensation regional or local? What is the effective depth of isostatic compensation? To what extent does the isostatic readjustment lag behind the addition of loads at the surface by deposition, as in river deltas, or lag behind the subtraction of loads in regions of long continued erosion? To what extent are anomalies in the direction and intensity of gravity attributable to surface geology even though the isostatic compensation may be substantially complete and perfect? It seems to me that the answers to all these questions are contained in the deflections of the vertical and the anomalies of gravity. The answers may be more reliably and accurately obtained the larger the area over which the deflections and anomalies extend on a uniform datum, and the greater the variety of the conditions at the stations. Experience indicates

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also that it is especially important to have some groups of stations with a very dense distribution, even in regions where there is believed to be little local disturbance. The road to progress seems to lie in the publication of the new large collection of deflections and anomalies as proposed, and in a keen analysis of the collection.

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STATUS AND NEEDS OF SEISMOLOGY

W. J. HUMPHREYS

STATUS

The present status of seisomology, at least in respect to popular interest and instrumental equipment, reminds one strongly of the proverbial man who locked his stable door after the horse was stolen. Perhaps, too, if the door had no lock at the time of the theft, in his excitement the owner of the horse bought the first lock he could find, then soon tired of the necessary routine of turning the key, and again became neglectful before the next thief came along.

Whenever any region is visited by a severe earthquake, everyone in the disturbed territory who has a dead seismograph under his charge is immediately galvanized into temporarily running it again, while many others in innocent excitement clamor loudly "Oh, for a seismograph, a seismograph," and various inventors come forward with marvelous designs. But all this voluble enthusiasm commonly is of short duration, while those who got their new toys soon find them less interesting and more exacting than they had imagined, and in the end avoid them as the wise man avoids the deadly upas tree.

And so it has come about that there are scores of seismographs all over the world that are of no value whatever—poorly designed, badly installed, and inadequately operated, or, better, perhaps, not operated at all, but just awaiting the time when someone will have the courage to consign them to their proper place—the junk heap.

But the situation is not wholly bad, for there are a few seismological stations at which valuable records are continuously obtained, although, in great measure, their equipments are more or less experimental and radically different, and the data thus secured all but as variously treated.

There has been, and there still is, much wasted effort in seismology; nevertheless all these independent explorations in many directions, these inevitable pioneer efforts, have served, as nothing else could, to make clear what some of the fundamental problems of seismology

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are, and how we should go about getting the data essential to their solution.

NEEDS

We know that seismology requires, as do few other sciences, international co-operation, or, at least, agreement among seismologists, the world over, unitedly to attempt the solutions of certain specific problems, and, therefore, to have comparable equipments and to assemble their records in much the same way.

Theory.—But first of all, now that the preliminary stage of this new science is over, we need, to guide us, a searching mathematical analysis of what to expect, as to velocity and period, of each of the several kinds of seismic waves, under this and that reasonable hypothesis in regard to the structure of the earth. We want to know, for instance, the details of the travel of the waves through the sedimentary layer, the granitic layer, and basaltic layer; and the combination effects of these layers on reflections, and on the so-called long-period or surface waves.

To push these problems, as they should be pushed, much beyond the stage to which they have already been advanced would demand exceptional ability in setting up and solving the equations applicable to elastic solids. The extraordinary difficulty of this problem, or, rather, host of problems, would leave us in despair of any marked progress in seismology, but for the fact that therein lies its appeal to the mathematical physicist. He loves the next-to-impossible problems, and here he has them in abundance.

Design of apparatus.—When the elastician has told us what this and that reasonable hypothesis predicts, instruments must then be designed to test these predictions, and to gather data that will enable the theorist to improve his hypothesis. Here, too, much is demanded—rigid mathematical analysis, ingenious designing, and skillful construction; for neglect of any one of the three means failure.

Location of stations.—The next thing to do, if we are to have an adequate study of seismology, is to determine where the instruments are to be located. The difficulties here are only practical, but, for all that, quite real. Certain regional problems of the highest interest to geologists and engineers may indeed present no serious difficulties in this respect. They can be provided for within the territory of a single government, and financed by a single institution or organization. In short, for this class of problems, co-operation and continuity, each essential to success, are easy to obtain. But that other class, the teleseismic problems, requires a distribution of instruments in various countries and, after that, a continuity of operation, and a unity of purpose, difficult to inaugurate, and all but impossible to maintain.

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Publication of data.—What particular seismological data shall we publish? Where shall we publish it? When shall we publish it? All these, and more besides, are important and pressing questions that cannot be rightly answered except by international agreement.

In short then, seismology is well established as a science, and blessed with enough difficult, unsolved problems to guarantee it a future full of healthful struggle and exciting interest.

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STATUS, SCOPE, AND PRESENT-DAY PROBLEMS OF METEOROLOGY

C. F. Marvin

Little is to be gained in this brief account of meteorology and its problems by attempting to state with any fullness the status and scope of the science.

The domain of meteorology is the entire atmosphere, and no boundaries of nations, continents, or oceans of any kind delimit its scope or problems.

For more than half a century the great nations of the earth have given meteorology a national status, either by the entire maintenance of national weather services in some form or other, or by subsidies or contributions in support thereof. At the present time, nearly all civilized countries of the world maintain more or less completely organized services.

The Southern Hemisphere and portions of the tropical regions of the globe are but poorly represented by observing stations, not merely because of the small proportion of land to water areas, but because of imperfectly organized services.

The contributions to meteorology from private observatories and special institutions were invaluable in the past, but the place and work of these are now almost completely occupied by the numerous national services.

The essentially international aspect of the science was early recognized, and harmonious co-operation among the nations has been secured through the so-called International Meteorological Congress, which had its origin in a conference held at Leipzig in 1872 and which has continued to function in a highly satisfactory manner up to the present time. Although its regular sessions were interrupted by the war, the organization was reconstituted at a conference held in Paris in 1919 by invitation of the French Government.

This international organization consists of so-called Congresses which

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are held at infrequent intervals. Delegates to a Congress include representatives of all the meteorological services and of the principal private observatories of the world. The permanent working body of the organization is the International Meteorological Committee, which at the present time consists of not more than twenty members, each of whom is a director of some national service. The work of the committee is specialized by the organization of so-called Commissions, which are in the nature of sub-committees charged with special fields of work.

At the meeting of the International Committee held in London in September, 1921, there were twelve commissions of which two were newly created in 1921. The names of a few of these will illustrate the nature of the organizations: Terrestrial Magnetism and Atmospheric Electricity; Maritime Meteorology and Storm Warnings; Meteorology and Agriculture, etc., etc.

The International Geophysical and Geodetic Union, through its section on meteorology, is a new and additional agency by which effective international co-operation, so essential to the future progress of meteorology, can be carried forward.

The International Meteorological Congress will hold its next meeting during the second week of September of this year at Utrecht, pursuant to the invitation of the Director of the Meteorological Institute of Holland, Professor Van Everdingen. The relations of the work of the International Meteorological Committee and that of the Section on Meteorology of the International Geodetic and Geophysical Union is an important topic on the agenda of the meeting.

As lack of time prevents a fuller consideration of these highly important matters, I must take up next some problems of meteorology.

PRESENT-DAY PROBLEMS OF METEOROLOGY

All the phenomena of meteorology are naturally confined to conditions in the earth's atmosphere, and man's first observations and problems were encountered in dealing with terrestrial conditions. It was soon known, however, that the heat reaching the earth from the sun was the ultimate cause of all earthly weather and climate.

Problem 1.—The sun and its radiant energy impressed upon the earth is the first great problem of meteorology. How much do we really know, and of how much are we ignorant, concerning solar radiant energy and its geophysical effects?

Conservative meteorologists have hitherto found the effects of solar *thermal* energy either constant in amount or slightly variable as it reaches the earth fully adequate to explain practically all the phenomena involved in atmospheric circulation. On the other hand, a

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few fanciful thinkers, little restrained by a grave paucity of both facts and theory, boldly announce that such solar phenomena as sunspots, very minute and as yet scarcely proved fluctuations from day to day in the intensities of thermal radiations of the sun, exercise important controls upon weather phenomena, growth of vegetation, etc. With even slighter basis of observed facts and more fanciful flights of imagination, a few boldly acclaim that climatic changes occur under the control of solar electric and magnetic emanations.

Here is a genuine problem of fundamental importance.

The meteorologists necessarily must depend upon astronomers and solar physicists for the unequivocal facts concerning the sun and its radiant emanations, and upon the magneticians for terrestrial data concerning phenomena in their domain. America may point with much pride to three great institutions which are unsurpassed elsewhere in the whole world and which are steadily supplying the solar and magnetic data needed in this problem. I refer, of course, to the Mt. Wilson Observatory and the Department of Terrestrial Magnetism, both of the Carnegie Institution of Washington, and to the Astrophysical Observatory of the Smithsonian Institution. Systematic observations from these sources as yet cover barely a score of years, about two sunspot periods, a length of time entirely too short upon which to establish obscure and unknown relations and to evaluate effects which are very certainly of small magnitude.

Finally, on the side of the facts in this problem we have what may be a great superabundance of meteorological data, because these began many years before the needed solar observations. On the other hand, meteorological data are bunched into certain geographic localities and are sadly lacking in others.

The solution of this great problem of solar emanations and our weather and climate is a study of statistical analysis and correlation. It is largely an arm chair problem of the analyst, not a laboratory job of experimentation.

The Weather Bureau, through the careful work of its technical staff, is *slowly, surely and sanely* advancing the science of meteorology with reference to this difficult problem of solar emanations and terrestrial weather and climate. *But everything depends upon intelligent interpretation of data and results.* This is a subject which cannot be discussed in the brief time now alloted.

Problem 2.—Passing from the sun and its emanations to our own atmosphere, we choose for our second problem—*The General Circulation of the Atmosphere.*

Meteorologists of the past, and many of the present day, accept without question the standard text-book versions of the primary wind

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systems of the globe. Must we not pause to ask ourselves if we are building upon a perfectly sound foundation of theory and fact? The basic theories of atmospheric circulation were first put upon a firm footing by the mathematical productions of Wm. Ferrel. His contributions are the more remarkable because they really preceded, by a decade or more, the general world-wide organization of numerous meteorological stations and the systematic collection of statistical data. Ferrel's equations were checked against the merest fragment of observed facts, but his general theories continue to hold an unquestioned place in meteorological science.

Let me state a few basic assumptions which underlie these theories and let us see if errors are not likely to be introduced. The old canal theory of interchange of warm and cold air between the equator and the poles calls for an over-and-under type of flow which on a stationary earth should take place along meridians. On a rotating globe, however, the northward moving warm currents must be turned to flow eastwardly while the southward moving currents are diverted to a westward course by the influence of the earth's rotation. There have been many doubts expressed as to the reality of this over-and-under type of flow, as a major feature of the general circulation, and both cloud observations and daily weather maps for the Northern Hemisphere at least seem to justify the conviction which many hold that thermal interchanges between the tropics and the poles are effected by flow and counterflow at the same levels as at the earth's surface; rather than the over-and-under interchange of the theory.

Furthermore, Ferrel has assumed that the Northern and the Southern Hemispheres constitute a balanced pair of atmospheres much as if there might be an impermeable wall or plane of separation extending indefinitely outward from the equator. At least, his theory takes no account of the very great annual transfer of air masses back and forth across the equator which we know must take place and is so exemplified in the historic systems of monsoon winds of the Indian Ocean.

The deepest thinkers among meteorologists believe a re-survey of world-wide meteorological conditions is called for to establish a more comprehensive theory of the general circulation of the air that will take better account of the winds of the globe as they actually appear on weather maps from day to day.

The solution of this problem requires (1) the prompt (telegraphic, if possible) collection of daily or twice-daily weather observations and reports sufficient to construct accurate *daily* weather maps for the entire globe or on separate polar hemispheres; (2) the study of such data by the meteorologist, the mathematician and the physicist, with

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a view to the *intelligent* interpretation thereof and the formulation of improved laws and equations of motions.

Obviously, this problem is of such magnitude that the collection of the necessary data and the issue of appropriate world weather maps, embracing and depicting not only surface conditions but, in addition, cloud observations at intermediate and high levels, including free air sounding, require international co-operation and co-ordination of effort of the most earnest and cordial character.

For a period of about six months during 1914 the United States Weather Bureau published its daily weather map of the Northern Hemisphere. It has not been practicable to resume this issue, which the war brought to an immediate termination, although the Bureau continues to prepare the manuscript maps which serve a highly useful purpose in its daily forecasts.

It is believed the time is near at hand when proposals for international co-operation may be made that some great nation be entrusted with the duty and responsibility of the issue of a truly world weather map based upon a suitable number of station reports, the total expense thereof to be equably apportioned among those in co-operation. The Weather Bureau contemplates proposals of this character, and the National Research Council, through the International Geophysical Union and Foreign Relations Committee, can undoubtedly be of great assistance in promoting results.

Problem 3.—I will assign to the third place in my list a group of problems all very closely related to Problem 2, but at the same time capable of separate work and effort. Time permits of presenting these only by title, so to speak:

(a) The ultimate cause of origin and sequence of the cyclones and anticyclones of extratropical latitudes.

(b) The expression *Centers of Action* has been current among meteorologists for a score or more of years. Are all in accord as to the physical reality of the thing connoted by the name? Where is the locus and what are the confines of these indefinite entities?

(c) What makes West Indies hurricanes, typhoons, and like tropical cyclones? How little more we know than the destruction wrought by these mysteries of tropical meteorology.

(d) *Ocean Meteorology and Marine Forecasting.* Full and detailed observations over the vast ocean expanses of the globe are almost impossible of attainment, but the near future promises most important extensions in this field of effort. The subject can merely be mentioned here and some discussion of it will be taken up at another time by the Chairman of Section (c) who has recently made some special study of the problem.

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Problem 4.—I include within this problem what we have come to call *Agricultural Meteorology,* which deals with the influence of weather on vegetation, particularly its influence upon animal and vegetable food and textile supplies of the nations and the world.

The greatest present obstacle to progress in this most important economic study is the great inaccuracy in data expressing acreage and yield, and no more important step for real progress can be made than that those agencies of the Government and the nations of the world should inaugurate at once plans for procuring really *accurate* figures on acreage and production of the big staple crops of the world.

The meteorologist engaged in the study of weather and crop relations is constantly confronted with the internal evidence of gross inaccuracies and lack of homogeneity in acreage and yield values.

Problem 5.—Meteorology in Aid of Aeronautics has become a new duty and responsibility devolving upon national services of the major nations. The nature and scope of the problem is obvious from the title. Its solution calls for many more observations by means of kites, pilot and sounding balloons than have been available in the past, also, a co-operation between the personnel of meteorology and aeronautics, in order that each may better understand the problems, needs and services of the other.

Problem 6.—Professional forecasting of the weather is a primary duty imposed upon national weather services generally. Without exception, almost no service attempts to make forecasts for long periods in advance, that is, for months, seasons, etc. I do not believe such forecasts are scientifically impossible, but no sound method is yet known by which they can be made with a sufficient measure of success.

The meteorological problem involved in long-range weather predictions is the problem of what are the *laws of the sequence of weather conditions.* This problem embraces, as one of its parts, the very popular question of *weather and climatic periodicities.*

Many claims have been advanced, and about the same number of skepticisms have been entertained, but as a fact very little is really known, either pro or con, and the subject is one needing careful and systematic study. One serious obstacle is the shortness of nearly all records of data. Little can really be done with long-time changes like sunspot periods and others of still greater length. On the other hand, if short periods of days, weeks, months, or a few years in length, actually exist and persist, abundance of data are available for their disclosure. Almost everything depends upon the use of adequate methods.

Problem 7.—Meteorological Education. Many problems in meteorology cannot be considered here for lack of time, but this brief cate-

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gory would be incomplete without mentioning the subject of meteorological education in the schools, and especially advanced education in the universities of the nation.

There is pressing need for higher training in dynamical and physical meteorology as a basis for the profession of weather forecasting of the highest type. The public, agriculture, commerce, and the industries are coming more and more to seek, utilize and demand advance information concerning the weather. The Weather Bureau is finding it increasingly difficult to recruit and maintain its staff of professional forecasters adequate for the increasing demands incident to nothing more than the normal growth of the nation. The great universities should make professional meteorology and forecasting a major course in the physical departments of education. The possibilities of future occupation for students in this field may not seem to be attractive under conditions as they now exist, but I am certain that if a reasonable supply of material and talent of this kind were once to become available it would soon find reasonable opportunities of employment.

U. S. Weather Bureau,
Washington, D. C.

STATUS, SCOPE, AND PROBLEMS OF THE SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

W. F. G. Swann

The work of the student of the earth's magnetic and electric phenomena naturally divides itself into two parts, first the study of the main phenomena themselves, and second the study of their causes and of such subsidiary phenomena as are bound up with them. As regards the main phenomena, we have on the magnetic side the study of the magnitude and distribution of the earth's magnetic field over the earth's surface, and its diurnal, annual, and secular variations. On the electrical side, we have the study of the magnitude and distribution of the earth's potential-gradient, of the atmospheric ionization and conductivity, and the diurnal, annual, and secular variations of these quantities. We also have a class of phenomena which are to some extent distinct, since they are associated with abnormal rather than with normal conditions in the atmosphere. I refer to phenomena associated with the thunderstorm and with the electrification of rain.

Imperfect as is our knowledge of the origin of the earth's magnetic and electric fields, however, we know enough about them to know that they are closely bound up with certain less obvious phenomena in such a way as to make the study of the latter a necessary complement to that of the other.

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We have reason to believe that the primary agencies concerned in the diurnal variation of terrestrial magnetism are currents induced in the upper atmosphere on account of the tidal motion of the atmosphere across the earth's lines of force. The magnitudes of these currents depend upon the conductivity to be assigned to the upper atmosphere, so that all phenomena likely to be associated with the production of such conductivity come under the natural scope of our study. We believe the aurora to be caused by the entry into our atmosphere of corpuscular rays of some kind from the sun, and to such rays we also look in part for an explanation of the conductivity of the upper atmosphere. We naturally expect, as indeed we find, a close connection between auroral phenomena and those of terrestrial magnetism. The closeness of the relation is increased by the known connection between these phenomena and magnetic storms. Thus, the study of the aurora, and of all matters concerned with it, such as the nature of the radiations responsible for it, the nature and composition of the upper atmosphere in which the luminiscence occurs, the theoretical aspects of the bending of the corpuscular rays by the earth's magnetic field, all these fall within the scope of our interest. The close connection between these phenomena and the sun's activity as exemplified in such matters as sun spots brings the sun itself within the field of our studies. Again, the existence of a state of high conductivity in the upper atmosphere has important consequences in respect of the transmission of wireless waves, so that the study of the transmission of such waves around the earth, and of the fading of signals become of importance to us; and, while speaking of wireless telegraphy, I must not omit to mention the matter of atmospheric strays which are evidence of some kind of electric disturbance, whose elucidation would be of great interest to the student of the earth's electrical behavior.

The study of earth-currents interests us, for two reasons; first in relation to their connection with auroral phenomena, and with the variations of the earth's magnetic field, and second, in so far as they may exist in part independently of these varying phenomena, and may be bound up with the earth's permanent magnetic field.

Any phenomena associated with a departure from the normal state of affairs is likely to form a clue in binding together the different elements of our study, particularly if that phenomenon is likely to have a direct influence on some of the main agencies concerned. The measurement of atmospheric and electric elements during an eclipse of the sun is consequently of considerable importance.

Turning to the purely atmospheric-electric side, our interest extends not only to the fields which I have mentioned, but also to various

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matters concerned with more or less pure physics, to the ionization which is known to occur in hermetically sealed vessels, and which may be attributed to a radiation of cosmical origin, or may arise from more local causes. The nature of the ionization produced by high speed corpuscles, and the penetrating power of such corpuscles are of fundamental importance in connection with theories of the earth's charge. The amount and distribution of radio-active material over the earth's surface, and in the atmosphere has an important bearing on the atmospheric conductivity at low altitudes, and the student of atmospheric electricity must draw very largely upon the information of the meteorologist in connection with air currents, and the various other meteorological features which so greatly influence the nature of atmospheric electric phenomena at low altitudes.

Finally, I must emphasize the importance to the cosmical physicist, of a close scrutiny of the facts and principles of pure physics. The situation in this regard is enhanced, moreover, from the fact that in dealing with a body of the earth's size we find that phenomena which would be quite imperceptible in laboratory experiments assume a degree of importance which is at times almost fantastic. Thus, currents started in wire circuits in our laboratories and left to themselves will not die out immediately. The inertia of the electric current will insure that they persist for a short time, but for a time so short that, in general, delicate means are necessary to register it at all. Currents started in a copper sphere of the earth's size, and left to themselves will take 10 million years to decay to one-third of their initial values as Lamb has shown. A current density of the order one hundred millionth of an ampere does not produce very startling effects in most laboratory experiments, but, a current density of this order in the body of the earth will give rise to a magnetic field equal to the whole of the earth's magnetic field. So the story goes, and he who would seek the origins of the earth's magnetic and electric phenomena must be prepared to peer into all sorts of possibilities and even to concern himself with the structure of matter and the problems which lie in the domain of the pure physicist. Moreover, in doing this, he must adopt a view point which is in some cases more fine grained than that of the pure physicist, for he must be prepared to seize upon the most minute possibilities in existing theory, and upon possibilities of modifying existing theories to extents which, while negligible for the purpose of the pure physicist may be for him the solution of some great problem of cosmical scale. A student of the subject must possess a rapid intuition, and a keen sense for orders of magnitude that he may see quickly what is likely to be important and what trivial. He must possess mathematical power to enable him to trace the consequences

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of the facts to their logical conclusions; but frequently, a mathematical problem chosen *ad hoc* leads to difficulties which no man can surmount, so he must possess a certain subtlety of vision, which will enable him to avoid the more difficult paths to his goal, and cause him to formulate his problems in such a way that while they lead to the information desired, they are possible of solution. Finally, he must possess a sound knowledge of the principles of physics, and above all of their logical connection with each other. He must not merely know the laws, but he must understand the structure; for, he will have to tamper with structure. He may have to remove a prop here and there, or modify the scaffolding occasionally, and woe betide him who tampers with a structure with which he is not familiar. He will assuredly produce many results, but alas for some of their consequences.

It seems that the time has come when the student of terrestrial magnetism will have to familiarize himself more and more with that great revolution in our ways of thinking exemplified in Einstein's General Theory of Relativity. Already we hear that Einstein has been successful in including terrestrial magnetism in his general scheme. Every student of the subject has felt that this step must come sooner or later; for, so fundamental is the change which the theory of relativity makes, not, of course, in the facts, but in our way of describing them, that to develop a theory of relativity for gravitation and leave terrestrial magnetism out would be to talk in two different languages in two different branches of physics. It may always be convenient for most practical purposes to speak in terms of magnetic fields and the like, just as it will always remain convenient for most purposes to speak in terms of the Newtonian theory of gravitation; but it is important that one who interests himself in the fundamentals of the subject, and seeks what he may choose to call the causes of the phenomena which he studies shall be fully conversant with those modern developments in thought in which the ideas of cause and effect exhibit themselves in such altered form.

I now turn to suggestions for problems which it would seem worth while to attack. First let me refer to a few pertaining more particularly to atmospheric electricity.

The earth's charge is leaving it at such a rate that 90 per cent of it would be gone in ten minutes were there no means of replenishing the loss, and there is a very important class of theory which attributes the replenishment to high speed corpuscles shot into the earth either from outside of our atmosphere or from the atmosphere itself. There are two great difficulties in such assumptions. The first arises from failure to detect any charging effect due to the absorption of these

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corpuscles by an insulated mass of metal, and the second arises from the fact that since, as far as our laboratory experiments go, a corpuscle moving with a velocity comparable with that of light should produce 40 pairs of ions in each centimeter of its path, and since the replenishment of the earth's charge requires the influx of 1,500 corpuscles per square centimeter per second, we should expect these to produce about 40,000 pairs of ions per c.c. instead of only about one ten thousandth of this amount as experiment shows to be the case. I have recently tried to remove the second of these difficulties by showing that corpuscles with velocities sufficiently near to the velocity of light should fail to ionize, but the first difficulty remains; and, while it is not unsurmountable in the case of certain types of corpuscular theory, it would be a great comfort if we could measure such a charging effect. I sought such an effect eight years ago, and more recently the effect has been sought independently by Von Schweidler, but in both cases without success. On the other hand, in view of the fact that auroral phenomena, which are attributable to corpuscular radiations from the sun, are concentrated so sharply in certain zones of the earth's surface, it would seem of the greatest importance that a search for this charging effect should be sought in those zones.

The second problem I have to suggest has to do with certain consequences which should result from the existence or non-existence of the supposed region of high conductivity in the upper atmosphere. I can illustrate the matter in this way. Suppose that there is no such condition as this layer and suppose that we have rain falling from a cloud to the earth, the rain being as it usually is, positively charged. The positive charge will not spread itself uniformly over the earth, because it will be held bound in the immediate vicinity of the cloud. In other words, the effect of a rain storm on the potential gradient would be practically local. Now, if there is a conducting layer in the upper atmosphere, the situation is changed. In this case the cloud sets up a difference of electrical potential between the layer and the earth, which is handed round more or less uniformly to all parts of the earth. On submitting this matter to calculation I find, for example, that if h is the height of the cloud and H, the height of the layer, the positive charge to be found on that half of the earth which is remote from the cloud is h/H of what it would have been if the charge had been uniformly distributed, and R/H of what it would have been if the layer had been absent, R being the radius of the earth. The upshot of all this is that, if there is no conducting layer, practically all of the charge should remain on the part of the earth to which it falls, after due allowance is made for conduction back to the atmosphere on account of the conductivity of the atmos-

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phere, whereas, if a layer is present, an appreciable part of the charge should be transferred to other regions of the earth. If then, at a number of stations in a region where it is raining, we measure the charge actually brought down by the rain, and the rate of accumulation of charge density on the ground after correction for the current back to the atmosphere, we have a means of testing whether or not the charge remains where it falls, and consequently of deducing certain information with regard to the presence or absence of a conducting layer. A practical method of making the test would be the following: Suppose we have a large insulated tray at the ground level, and exposed, of course, to the potential gradient. Allow the rain to fall into this tray after connecting it to earth and then insulating it. Keep the potential constant and zero by feeding electricity into it from a condenser in a manner of which the details will be sufficiently obvious to need no description. It will be obvious that in cases where the rain is sufficiently steady and prolonged to permit of a steady state being attained, measurements of this kind, at any rate when made simultaneously at a number of different places, will lead to information as to the rate at which charge is passing from the regions immediately below the cloud to those more remote.

Another avenue of attack on the conductivity of the upper atmosphere is to be found through the medium of wireless waves. If the transition from practical non-conductivity to high conductivity is sufficiently sharp, marked reflection of electro-magnetic waves should result; and, by suitable arrangements, the details of which I must not enter into, it should be possible to measure the time taken for wireless waves to travel to the layer and return, and so deduce the altitude of the layer.

The great importance attaching to measurements of the atmospheric elements at high altitudes, and particularly of the residual ionization in gases is so self-evident that it is hardly necessary to do more than refer to it in passing.

The problem of the conductivity of the air over the great oceans is by no means satisfactorily settled. The conductivity is far greater than can be attributed to the radio-active materials in the ocean itself, or in the air over it. It has been customary to invoke, for the explanation of the ionization over the ocean, a penetrating radiation of cosmical origin whose assistance has also been invoked to account for the ionization which is known to occur in a hermetically sealed vessel free from radio-active materials, and suitably shielded from such radiation of ordinary gamma-ray type as may come from radio-active materials in the surroundings. Unfortunately, recent experiments have thrown considerable doubt upon the reality of this pene-

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trating radiation, at least as to its existence at low altitudes; and, it may be that, in order to account for the residual ionization in vessels and for the conductivity of the ocean's air, we shall have to resort to the assumption of a spontaneous ionization of the gas itself. A full understanding of the origin of conductivity in the lower atmosphere thus renders it imperative that we strive to solve this question of the origin of ionization in closed vessels (or more important still, the origin of the ionization which would occur in the air in the absence of the vessel) in order that we may know whether it is really necessary to invoke an external radiation, or whether the causes of the ionization are inherent in the gas itself.

I now turn to a few matters having a bearing upon the earth's magnetism. If, as seems likely, the earth's magnetism is bound up with its rotation, a knowledge of the magnetic fields of other heavenly bodies, and attempts to detect the magnetic fields of rotating bodies of laboratory size become of importance, since such information gives us a clue to the way in which the magnetic field varies with dimensions, angular velocity, density, etc. Thus to illustrate the point in question, suppose we were to seek an explanation of the earth's field on the basis that, on account of the centrifugal force of the earth's rotation, the free electrons in its interior must suffer radial displacement, with a resulting production of a magnetic field on account of the rotation of the electro-static distribution thus brought about. As a matter of fact, the field in this case can be calculated, and amounts to only 10^{-23} of the earth's field, but suppose that there had been some element in the calculation which prevented our obtaining the actual magnitude, and gave us only the form of the expression for the field. The field on the equator at the surface in this case comes out proportional to $\omega^3 a^2$ where ω is the angular velocity and a the radius of the sphere. It would thus result that on such a theory, a sphere of radius 10 centimeters rotating at a speed of 100 revolutions per second in the laboratory would have a field over a hundred thousand times that of the earth, while the sun should have a field only half that of the earth. Our knowledge of the absence of fields of the above order of magnitude in the case of bodies rotating in the laboratory is therefore sufficient to rule such a theory out of court, and the fact that the sun has a magnetic field of about 50 gauss is additional evidence in the same direction. A large class of theories give the magnetic field proportional to $\omega a^2 D$ where D is the density of the substance. On such theories, the existence of a field of the order 0.5 gauss at the earth's pole would correspond to the existence of a field of the order, 50 gauss at the corresponding place on the sun, a result well in harmony with Dr. Hale's conclusions as to

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the magnitude of the sun's field. On the other hand, this class of theory would give quite inappreciable fields for bodies of laboratory dimensions rotating with attainable angular velocities. Such a type of theory would, moreover, lead to the conclusion that we should have but little hope of detecting magnetic fields in the stars other than the dwarfs, for, expressed in terms of mass m rather than density, the expression makes the field proportional to $\omega\, m/a$, so that for given mass and angular velocity, the field is small in proportion as the radius is large. Even the giant stars have for the most part, masses only comparable with that of our sun, so that, on the basis of such a type of theory as that under discussion, the large radii would cut down the surface magnetic fields to very small values.

I now turn to a suggestion which is rather speculative as to its possibilities, but which is perhaps of sufficient interest to warrant mentioning. The question of the permeability of the earth's interior is one which has interested students of the subject, particularly in relation to the possible effects of combined pressure and temperature conditions to be found within the earth. It would therefore not be without interest to make a direct measurement of the average permeability of the earth. The possibilities in this connection are perhaps not as visionary as might be thought at first sight. Suppose we have two cables parallel to each other around the earth's equator, and start a current in one of them. We shall get an induced current, and a definite time integral of current in the other. The magnitude of the latter will depend upon the dimensions of the circuits, the value of the primary current, the resistance of the secondary circuit, and the average permeability of the earth, and will vary by a factor of the order of magnitude of 3 according as the average permeability is comparable with unity, or large compared therewith. Now a simple calculation will show that by starting a current of one ampere, in the primary cable, the order of magnitude of the induced flow in a secondary cable, of resistance say 10000 ohms will be 0.017 coulomb, a very large quantity when considered in relation to what is measurable with a sensitive galvanometer. It will be obvious that the ideal condition stipulated above is not necessary for the purpose of obtaining measurements from which conclusions could be drawn. It is not necessary for the circuits to be immediately adjacent, or to be drawn around the equator, or to be parallel to each other. In fact, a little consideration will show that all that is necessary is that the dimensions of the circuits shall be comparable with the depths to which we wish to extend our information as to the permeability, and their distance apart must not be greater than is comparable with their dimensions. The practical question involved is of course

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how far it would be possible to utilize existing cables for such a project as this.

It may perhaps be worth while to call attention to the possibilities inherent in the use of a large coil for automatically recording the instantaneous rate of change of the earth's field at any place, as distinct from what is usually measured, the actual value of the field. The matter may be illustrated by the following example: The diurnal variation of the earth's horizontal intensity is of the order of magnitude of 10^{-8} C.G.S. unit per second. A square coil with sides 100 meters long, wound with 10 turns of wire would give, on the above account, an e.m.f. of 10 electro-magnetic units, or 10^{-7} volt. If the coil were wound with wire of gauge 10, it would have a resistance of 12 ohms, and would therefore cause a current of 0.5×10^{-8} ampere in a galvanometer of resistance 8 ohms. A properly designed galvanometer would give a deflection of about 2 mm. for this current at a scale distance of 2 meters. Of course 2 mm. is not a large deflection, but greater deflections could be obtained by the use of a larger coil, or a coil with larger number of turns of the same kind of wire, in conjunction with a suitably chosen galvanometer, and the above calculation will serve to indicate the possibilities in this connection.

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STATUS, SCOPE, AND PROBLEMS OF THE SECTION OF OCEANOGRAPHY

G. W. Littlehales

As an emissary from the Section of Oceanography, by designation of its Executive Committee, I am to make the summary statement of the scope and problems in relation to the science whose field is the oceanic expanse, covering an area which exceeds, by more than 80 million square miles, the total land surface of the globe and occupying basins whose cubical content is estimated to be fourteenfold greater than the bulk of all the lands in the world above sea level. The indications are that throughout nine-tenths of its extent, the depths are greater than one mile; throughout two-thirds of its extent, the depths are greater than two miles; and throughout 10,000,000 square miles of its expanse the depths exceed three miles. Many high mountains rise from the foundations of the oceanic basins, sometimes culminating in emergence above the surface of the waters; and many deep depressions sink below the general level of the bottom.

In the Philippine Deep, a sounding of 5,352 fathoms near the Island of Mindanao marks the greatest depression hitherto discovered

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in the earth's crust—a depression so profound that if the highest elevation in the world above sea level were set down within the trough, the summit would yet be 3,000 feet beneath the surface of the sea.

Oceanography is defined as comprehending "the investigations which deal with the form and divisions of all the marine areas on the surface of the globe, the winds that blow over the surface waters, the contour of the ocean bed from the sea-level down to the greatest depths, the temperature, the circulation, the physical and chemical properties of sea-water, the currents, tides, waves, the composition and distribution of marine deposits, the nature and distribution of marine organisms at the surface, in the intermediate waters, and on the floor of the ocean, as well as the modifications brought about in living things by the conditions of their existence, the relations of man to the ocean in the development of commerce, fisheries, navigation, hydrography, and marine meteorology. All this vast assemblage of knowledge, which embraces some aspects of astronomy, geography, geology, physics, chemistry, and the biological sciences, makes up the modern science of Oceanography."

It is worthy of note by geophysicists that the accepted gauge and shape of the earth's crust have been derived altogether from continental arcs without measurements over the 71% of the globe's extent occupied by the ocean.

In the foundation upon which the future superstructure of oceanography is to be raised there must be the configuration of the basins, which are the containers of the oceans; and in the other branches of geophysics, as well as in oceanography, the mapping of the two-thirds of earth's surface which is covered with water is doubtless of an importance second only to the importance of mapping the one-third which is comprised in the land areas.

May it be pardoned as an instance of the frailty of human nature if I seem to incline too far to a belief in the saying that "coming events cast their shadows before them," when I point to the recent survey made in 38 days by two vessels of the Navy of a tract of 34,000 square miles of the bottom of the Pacific Ocean, bordering the State of California from San Francisco to San Diego, as an evidence giving grounds for hope in the feasibility of accomplishing the mapping of the oceanic basins by proceeding along the avenues of cooperation among nations that have been opened in the International Union of Geodesy and Geophysics of the International Research Council.

The position occupied by water in the economy of Nature is most remarkable. Everywhere natural conditions are influenced and molded

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by its wonderful properties, and yet it is nowhere told how much water there is in the world. But we do know that the presence in the oceanic basins of 324,000,000 cubic miles of this substance having the highest known capacity for heat—which may be gauged by the statement that the specific heat of sea water is about thirty times that of mercury—must constitute the ocean a dominant factor in terrestrial physics, exercising a governing influence through its circulation upon heat transference and upon climate and the development of vegetation, and, by the enginery of its variations in physical and chemical condition from season to season and year to year, promising, when it comes to be understood, to enhance all those wealth-producing sources which operate in seasonal cycles.

I have elsewhere given a summary, in the publications of the American Geophysical Union, showing the means by which, from the unfathomed state of the middle of the nineteenth century, knowledge of the physical conditions in the depths of the oceans has advanced to an approximate conception of the conditions which prevail throughout the various ocean depths—conditions of movement, of temperature, of pressure, of the penetration of light, of gas content, of salinity, of life. Only a general idea of the contours of the ocean bed has been attained, and only a general idea of the bottom deposits covering that bed.

Although there is as yet little ground upon which to base general conclusions, the diversification found to characterize those tracts about which most has been learned appears to support the view that the ocean basins are extensively featured with orographical formations culminating at various depths below the surface of the ocean.

In every stage of the investigation beneath the surface of the ocean, invention has been the resource leading to progress. Our knowledge of the conditions in deep water, and all that takes place beneath the surface, must continue to be dependent on the correct working of instruments, the action of which is, for the time, hidden from sight. The sparse and disconnected observations of the physical elements obtained by means of indicating instruments, unstandardized among themselves, have advanced oceanography in the exploratory stage, but will not fully serve the ultimate purpose of investigating the ocean from the standpoint of thermodynamics. For this purpose continuous records are required, and, hence, the important problems of the present time include the production and perfection of instruments adapted for making continuous records, both at stations and in transit, of such physical properties of the sea as temperature and salinity, in vertical as well as in horizontal distribution. Oceanographers have already commenced to obey the modern tendency in physical research to

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replace indicating instruments by recording instruments. The later advances in the science of the tides are ascribable to the continuous recording tide-gauge.

It is by this course that the shadowy evidences of significant oscillatory, pulsatory, and vortical movements in the depths, which have been encountered in oceanographical research, can best be examined and extended for the fulfillment of the purpose of making known their origin and nature. The Japanese have shown the presence in their seas of standing waves, like those known to exist in lakes. Variations in physical condition have also been observed which are most naturally explained by the progression through the body of the ocean of great undulatory movements, like the waves which physicists observe on the boundary surface between media of different densities. The solution of the problem here presented is looked upon as one of the greatest importance both from the standpoint of dynamic oceanography and of biological oceanography. And of equal importance to the oceanographer of the future is to learn what takes place when wind blows over water, and hence the relation between wind and current. The currents of the ocean seem to be subject to a sort of pulsation of which little is known as yet.

Of great significance is the appeal of oceanography for international co-operation seen on all sides in the recognition by oceanographers of the fundamentally world-wide and hence continental and intercontinental nature of the phenomena, and the national and international character of the scientific and economic results to be developed, and the necessity for the application of resources that come only at the call of nations co-operating together. In every department of science the annals of knowledge supply abundant evidence of the importance of method. In recognition of this, it was with unanimous approval that the International Section of Oceanography, meeting in Rome in May, 1922, made provision for the preparation and publication of an International Manual of Oceanography.

U. S. Hydrographic Office,
Washington, D. C.

THE YEAR'S PROGRESS IN VOLCANOLOGY

ARTHUR L. DAY

The progress of volcanology suffered in two important respects as a result of the War. The German undertaking, under the leadership of Branca of the Berlin Academy, which in many respects was the most comprehensive plan for volcano study ever seriously contemplated, was dropped. A second plan, almost equally imposing, was started just before the War by Friedlaender at Naples. A beautiful

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laboratory overlooking the city and within sight of Vesuvius was constructed and a journal, the *Zeitschrift für Vulkanologie,* now in its ninth year, was started. This splendid laboratory was taken over by the Italian Government during the War, and, although its return has been promised, its resources have been so considerably impaired that it will be some years before a full return to the pre-war plan is possible. The *Zeitschrift* was continued by Friedlaender from Switzerland by the issue of occasional numbers, but here also a considerable time must elapse before its pre-war status is fully re-established. It is altogether likely that Friedlaender's recent visit to the volcanoes of Mexico and Hawaii will give new impetus to the activities both of the laboratory and its journal.

In compensation for this diminution of activity in Europe the establishment of systematic studies of volcanism in the Dutch East Indies promises to be most fruitful. Founded in 1917 by the Dutch Colonial Government, the records of this work already fill four volumes (*Vulkanologische Mededeelingen,* published in the Dutch language in 1921 and 1922) containing not only records of a wide variety of volcanic outbreaks, but also of sand flows and hot springs. Indeed the record of the eruptions which have occurred in Java and Sumatra during the last few years appears to be very complete.

The administration of this undertaking has taken the form of a commission modeled after the Imperial Earthquake Investigation Commission of Japan, and if appropriate support is provided will offer a continued service to the Meteorological Service.

In this country the most active work is at present being done by Professor Jaggar's Hawaiian laboratory, now under the direction of the U. S. Weather Bureau, and by the Geophysical Laboratory of the Carnegie Institution of Washington. Both of these institutions have been interested since 1912 in establishing upon a stable basis the study of the physical and chemical forces underlying volcanic activity, and both have issued a considerable number of publications in this field, some reasonably complete and some still tentative, and both have in hand more or less definite plans for future development. In particular Professor Jaggar has brought together the necessary funds for a number of borings in the vicinity of Kilauea crater and has already discovered an altogether unexpected temperature gradient both immediately adjacent to the lava basin and in the older deposits known locally as the Sulphur Banks. In the three borings so far made, one of which has reached a depth of nearly 100 feet, no temperature above the boiling point of water corresponding to that elevation has been found. In the case of the boring near the active lava basin this must

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have the effect of revising considerably our notions of the dissipation of heat through thermal conductivity.

On the chemical side the borings have served once more to emphasize the participation of water in all of the relations there prevailing, but have not thus far yielded any new data.

The Geophysical Laboratory has completed its survey of the outbreak at Lassen Peak from 1914 to 1917 and has announced what appears to be a plausible explanation of the volcanic phenomena there, which differ considerably from those studied elsewhere in that the temperatures have been found to be very low in view of the violence of the outbreak. This new hypothesis may be expected to have the effect of stimulating further observation of volcanoes of the explosive type in order to determine whether the hypothesis is to find general application or will merely serve to explain an unusual local condition.

A somewhat more elaborate study of the various types of thermal springs associated with volcanism has also resulted from these studies at Lassen Peak. The latter study of hot springs has not been published and the hypothesis in explanation of the mechanism of the activity is thus far only tentatively announced.

The Geophysical Laboratory was also privileged to join with the National Geographic Society in a study of the Katmai eruption of 1912 and the remarkable sand deposit and fumaroles of the Valley of Ten Thousand Smokes. These have been studied both from the geological and the chemical viewpoint, and a number of facts established which appear to be novel in the science of volcanology. So great an extent and intensity of fumarolic activity has perhaps never been witnessed before and the character of the hot sand flow covering several square miles is in many respects unique. Some of the results of these studies have already been published by the National Geographic Society.

Regarding the recommendation made by the Section last year that effort be exerted to secure a complete record of all volcanic outbreaks, it may be of interest to the Section to know that Professor Karl Sapper of Würzburg is continuing his chronological record, and that he now has in preparation a book upon this and other recent work.

On the whole, therefore, although it is not possible to announce a full return of pre-war interest in the study of volcanism, this field of activity has certainly not been lost sight of, and further intensive studies may soon be expected from Japan, from Italy, from the Dutch East Indies, and from the United States.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

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STATUS AND PROBLEMS OF GEOPHYSICAL CHEMISTRY

ROBERT B. SOSMAN

The subject-matter of geophysical chemistry was defined three years ago, upon the organization of this Section, as "the physical properties and chemical reactions of the substances and aggregates that make up the Earth." The Section thus occupies the position of a kind of physico-chemical technical adviser to the other Sections of the Union. The members of Section (g) like to feel that their work is fundamental and necessary to the work of all the other Sections. They feel that if research on the physics and chemistry of Earth materials were abandoned entirely, the result would be that while progress in the other branches would by no means cease, it would be progress only of the kind that is easily foreseen, the kind of progress for which an Appropriations Committee can make detailed and specific appropriations covering several years ahead; this is desirable, but we must also strive for the kind of progress which stands out in the history of science when viewed from a distance of fifty or a hundred years, the kind which starts unexpectedly and goes in unforeseen directions. Such advances are dependent upon the development of new methods and instruments and the discovery of new facts in physics and chemistry.

In the organization report just referred to, the subject-matter was roughly classified into two principal groups: (a) Materials at the Earth's surface, and (b) Materials in the Earth's interior. Each was further subdivided into (1) Individual chemical substances, such as calcium carbonate; (2) Aggregates, such as granite; and (3) Larger units of matter, such as glaciers. There is not time for an exhaustive review of the progress of knowledge in these different branches, and I shall, therefore, simply mention various items that come to mind as illustrating the present status of research in fundamental geophysics and geochemistry, as seen by the laboratory investigator.

Individual Substances.—The Geophysical Laboratory of the Carnegie Institution is still the only endowed laboratory devoting the major part of its attention to research in this field. Important papers marking progress in our knowledge of the silicates have been published since 1920, and include papers on the system SiO_2:MgO:CaO, the augites, the melilites, potash feldspar, and the silicates of barium and strontium.

University laboratories in this country in which similar work is being done include Princeton (silicates), Oberlin (colloidal silica and other oxides), Illinois, Stanford, and Rice Institute (colloidal oxides).

Mention should also be made of valuable data on silica and other important oxides contributed by the research laboratories of manufacturing companies, such as the Harbison-Walker Refractories Company.

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Governmental institutions have also contributed. For example, we have from the National Museum the continuation of important data on meteorites and the chemical properties of various minerals; and from the Bureau of Chemistry of the Department of Agriculture, work on the constitution of silicates.

The standard reference books for information on the individual chemical substances of the Earth's surface remain, as for some years past, Clarke's *Data of Geochemistry,* Hintze's *Mineralogie,* Dana's *Mineralogy,* and Doelter's *Mineralchemie.* There is a pressing need for a general work on lines more nearly related to the present current of advance in physical chemistry than those named.

Foreign Work.—Some work on the Earth-forming oxides, begun in Norway a few years ago, seems to have been abandoned for want of funds, while to balance this loss a new laboratory is under construction in Sweden, in which it is planned to do research on silicates. The impoverishment of central Europe has greatly diminished the contributions from that quarter, an important source of supply now being industrial laboratories, which in the nature of the case can publish only what is not highly valuable to the industry supporting the work. A geochemical journal, the *Chemie der Erde,* seems to have perished with the completion of volume 1 in 1920, and the *Silikat-Zeitschrift* has not been heard from since volume 2, 1914. On the other hand, *Tschermak's Mineralogische und Petrographische Mitteilungen* has been revived, after a lapse of five years, with the aid of Austrian, American, and Swedish funds.

Plans were made a few years ago for a laboratory in England similar to the Geophysical Laboratory in Washington; it is to be hoped that these plans will be put into execution soon. Some good work has been done in England on silica, principally for its industrial application. In Japan, work on the Earth-forming oxides is being done in several university laboratories, and several new periodicals, including the *Japanese Journal of Astronomy and Geophysics,* are making available, in English, papers which might otherwise remain inaccessible to most of us because of their original publication only in the Japanese language.

Aggregates.—That branch of geophysical-chemical work which I have classified as work "on the properties and reactions of aggregates" has made progress in the continuation of contributions from the Geophysical Laboratory and the Geological Survey on the composition of the igneous rocks and of the Earth's "crust" as a whole; also papers on the principles governing the differentiation of an igneous magma by crystallization under the active influence of gravity, and the development of pressure in a volcanic magma as a result of crystallization.

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On the movements of magmas there is an important theoretical contribution showing how gravitational energy may be converted into heat energy within a magma by the process of extrusion from a region of higher to a region of lower pressure.

Compared with the work on igneous rocks and magmas, comparatively little geochemical or geophysical work has been done on metamorphic or sedimentary rocks. Work has been done in some of the directions suggested by Dr. Vaughan in his report on "Research on marine sediments" at the 1922 meeting of this Union, but it is rather to be classed as geological research—the study of natural processes not under experimental control.

The Larger Units.—In the group of researches on the larger units of the Earth and on the Earth as a whole there should be mentioned such contributions as those from the Coast and Geodetic Survey on the Earth's field of force, from the University of Chicago on the mathematics of isostasy, and similar strictly geophysical contributions which are, however, of such particular interest to the Section of Geodesy or other Sections that this passing mention is sufficient.

Among researches bearing on problems of the Earth's interior should be mentioned the recently published data from the Geophysical Laboratory on the compressibilities of minerals and rocks over a wide range of pressures. These data confirm and greatly extend the work of Adams and Coker, and make possible some important deductions regarding the Earth's rigidity, and its properties with respect to earthquake waves.

Future of the Section.—I have referred at the beginning of this report to the possible usefulness of this Section as a technical consultant to the other Sections of the Union. In turn the members of this Section also have interests of their own, closely allied to physics, chemistry, and geology, in which interests they can receive valuable aid by consultation with the geodesists, seismologists, and the other groups in the Union. The most useful activity of the Section at this annual meeting would seem to be, therefore, to meet jointly with one of the other Sections to discuss problems of common interest.

Such a meeting has been arranged this year with the Section of Volcanology, and the subject chosen is "The temperatures of hot springs and the sources of their heat and water supply." The formation of hot springs has often, but not always, accompanied visible or historically recent volcanic activity. On the other hand, hot springs persist in regions where the volcanic activity is of very ancient date, and even in regions where no connection with any igneous rocks can be proved by geologic evidence alone. What is the source of the heat under these varied circumstances, and—a matter of equal interest—

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where does the water come from? Speaking broadly, the physicists and chemists have evidence which inclines them to believe that most of the water has come down fairly recently in the form of rain. The geologists and volcanologists, on the other hand, impressed by the evidence of the large part played by water in the formation of igneous rocks, are speculating as to where that water has gone in the past, and incline to the belief that many hot springs represent water which is now being released by crystallizing magmas.

By such meetings as the one just mentioned we may hope to eliminate those differences of opinion which are due mainly to the possession of different kinds of information by the different groups.

This plan raises the question, however, whether a separate organization of Section (g) is necessary or desirable. At the meeting of the International Union there seemed to be no interest in the formation of any corresponding international Section, the opinion being that the subject-matter is so much more closely allied to physics, chemistry, and geology that any diversion of interest is to be avoided. This is a question of organization and administration which may be best referred to the Executive Committee of the Union.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

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RESOLUTIONS

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RESOLUTIONS ON SCIENTIFIC QUESTIONS ADOPTED BY THE AMERICAN GEOPHYSICAL UNION, APRIL 19, 1923

(a) That the National Research Council be requested to do whatever may seem practicable to it towards inducing authors of scientific papers to give postal addresses.

(b) Whereas, The United States statutes at large, Vol. 37, p. 913, provide that

> "Hereafter the Executive shall not extend or accept any invitation to participate in any international congress, conference or like event, without first having specific authority of law to do so;" and

Whereas, Since other provisions of law make it impossible for officers of the government to attend and participate in an official capacity in any international foreign congress, convention, meeting or gathering, thus greatly embarassing the scientific departments of the government in conducting the important duties and responsibilities devolving on them, and since the principal object of such congresses, conventions, meetings, or gatherings is to secure between nations the most effective and profitable co-operation in scientific matters; therefore be it

Resolved, That the American Geophysical Union recommend to the National Research Council that appropriate action be taken to present to the Congress of the United States the disadvantages resulting from the effects of the laws referred to above with the object of securing the necessary legislation permitting the Executive and the heads of the various departments to designate duly accredited representatives to attend international foreign scientific congresses, conventions, meetings or gatherings. This legislation should apply especially to meetings of the International Research Council and its branches, and the International Meteorological Committee and like organizations.

(c) That the National Research Council be requested to consider, if found desirable, the question of the publication of seismological data; what data to publish, where to publish, when to publish, and the form of publication.

(d) That the National Research Council be requested to secure if possible a mathematical discussion of the transmission of seismic waves through the earth, and associated phenomena.

(e) That the National Research Council be requested to secure a study of the transmission of artificially produced seismic waves.

(f) Whereas, progress in meteorology and day-to-day weather forecasting demands a map as complete as possible embracing the entire

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northern hemisphere or even the entire globe, as far as this may be feasible, and whereas, Such an undertaking requires complete and effective co-operation between all the nations of the globe conducting systematic meteorological observations; therefore, be it

Resolved, That the American Geophysical Union endorses the project of securing a daily weather map of the northern hemisphere, based on telegraphic and radio reports of observations, to the forthcoming International Meteorological Conference to be held at Utrecht, Holland, in September, 1923, and further recommends that such action be taken as may lead to such international co-operation as will result in some one government undertaking the collection of the necessary observational reports and the preparation and publication of a daily map of the northern hemisphere and the distribution of the same to the participating governments.

With the inauguration of this work the circulation of the atmosphere, and other phenomena, as exhibited on a series of maps of this kind could be submitted to the students of the world for the advancement of the science of meteorology and improvement of the forecasting of the weather. It is suggested that the expense of such an undertaking, as far as this relates to the actual compilation and publication of the map itself, should be met either by the sale of the maps or by definite contributions from the co-operating nations.

(g) Whereas, Two resolutions reading as follows were adopted by the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union at its meeting at Rome in 1922:

> "That national committees be requested to designate, if possible, one observatory in their respective countries for international intercomparisons of magnetic instruments, and to secure intercomparisons of magnetic instruments within their own countries at least once within the course of three years.
>
> "That it is desirable there should be in every country at least one observatory making systematic atmospheric electric observations (especially of potential gradient, earth-air currents, conductivity, and number of ions), which are intercomparable amongst themselves and comparable with similar observations made in other countries;" therefore be it

Resolved, That the American Geophysical Union designate the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey and the Standardizing Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, working in conjunction, as the observatories in the United

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States to function in accordance with the first of the two Rome resolutions quoted above; and be it further

Resolved, That the American Geophysical Union endorses the second Rome resolution mentioned above and recommends the early establishment of such an observatory, without at present designating a particular observatory in order not to tie the hands of any organization which may find it possible to carry on the work specified in the resolution in question.

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ABSTRACTS OF REPORTS AND PAPERS

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SECTION OF GEODESY

ON THE ACCURACY OF TIME DETERMINATIONS

R. H. Morgan

Recent intercomparisons of wireless time signals show variations of 0'.2 to 0'.3 in the time from one observatory as compared with that from others, and suggestions have been made that such variations may be due to the astronomical observations, and that longitude work may be subject to similar uncertainties. This paper gives the results of several different investigations into the differences in clock corrections as determined from observations on the different instruments at the U. S. Naval Observatory, on over a thousand nights in the last twenty years.

From these comparisons it was found that the clock corrections determined from definitive reductions of simultaneous observations on two standard instruments rarely differ as much as 0'.1, and that the average difference is 0'.03. The probable error of a clock correction is 0'.014. The large instruments hold together within 0'.03 for a number of years at a time.

It was also found that the systematic or irregular variations of 0'.1 or 0'.2 which occur in time signals are more or less due to the provisional nature of the observations and reductions used, and that by properly planning the provisional work such variations in the preliminary times may be partly eliminated and partly corrected for by later definitive reductions; and that longitude determinations need not be subject to uncertainties of this size.

U. S. Naval Observatory,
Washington, D. C.

THE ACCURACY OF LONGITUDE DETERMINATIONS BY THE U. S. COAST AND GEODETIC SURVEY BY WIRE SIGNALS AND GENERAL FERRIÉ'S PROPOSED RADIO LONGITUDE NET

William Bowie

Almost from the beginning of telegraphy the U. S. Coast and Geodetic Survey determined differences of longitude by telegraph, and a network of lines between longitude stations has been spread over this country. An analysis of this work is opportune, as determinations of differences in longitude by wire signals will soon be superseded by work in which radio signals are used. It is important that the determinations by radio shall not be less accurate than the old work.

In 1897 an adjustment of the longitude net was made in which 63

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differences of longitude were used. The average correction to a difference was 0'.019. There were 36 corrections less than 0'.02 and only two greater than 0'.04. Since 1897 new determinations have been fitted into the adjusted net.

Since 1897, there have been determined 98 differences of longitude forming all or parts of 18 closed loops. Of these, 57 received corrections of 0'.01 or less, while only 9 differences had corrections greater than 0'.02. No correction was as great as 0'.03.

During 1922, seven differences of longitude by radio signals were determined. Preliminary results indicate the same accuracy as that obtained in wire longitude determinations.

Gen. Ferrié of the Bureau of Longitudes, Paris, has a comprehensive plan to determine the longitude of fundamental stations around the world by means of radio signals. His plan has received much attention from astronomers and geodesists. Undoubtedly the work contemplated by Gen. Ferrié's plan will be done in the not distant future, but there is some doubt as to the advisibility of incurring the expense that would be involved in having many stations occupied simultaneously, as is proposed by Gen. Ferrié.

His plan is practicable, in so far as accuracy is concerned, provided that methods are adopted which will eliminate systematic errors in the time observations, and provided that the radio signals are received automatically, and that corrections are applied for the reaction time of the various pieces of apparatus used in sending and receiving the signals.

The use of radio greatly enlarges the areas within which accurate longitude determinations can be made.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE ERRORS WHICH MAY BE EXPECTED IN RADIO LONGITUDE DETERMINATIONS CAUSED BY THE AUTOMATIC SENDING AND RECEIVING APPARATUS

E. A. Eckhardt

It seems to be generally agreed that the time observations as now made by astronomical methods do not yield values which may be relied upon beyond the nearest 0'.01. This fixes the magnitude of the time errors which is admissible in radio transmitting and receiving apparatus when they are used for time-signal work in longitude determinations.

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It is those parts of the apparatus which involve mechanical and electrical inertias, which are most likely to lead to lags and possible errors. Telephone diaphragms, relay armatures and relay coils are examples.

Electro-mechanical relays are used considerably, both in signal-sending and signal-receiving apparatus. The magnitude of the lags and their constancy are considerably affected by the manner in which the relays are used. Obviously that adjustment and arrangement which provides the quickest current changes in both the controlling and controlled circuit and the quickest motion of the armature will result in a minimum of lag. Relay users, however, frequently do not follow the practice that this would suggest. A method of studying relay performance, with special reference to magnitude and constancy of lags, was outlined and some typical results were presented and analyzed.

The problem of using relays in receiving radio signals was discussed. Constancy of lag can not be obtained if the relay operating current changes with signal strength. The nature of this difficulty was discussed in some detail and its avoidance by using a radio receiving circuit which is itself of the relay type was considered. The field-service apparatus now in use by the U. S. Coast and Geodetic Survey for radio time-signal recording is of this type. Its lag errors are within the limits required to make it available for use in exact longitude determinations. Where the astronomical observations are made at a field station instead of a fixed observatory, the field-service design of this apparatus makes it especially available for this purpose.

Bureau of Standards,
Washington, D. C.

THE PLACE OF GEODESY IN THE WORK OF THE COMMITTEE ON SEISMOLOGY OF THE CARNEGIE INSTITUTION

ARTHUR L. DAY

An outline was given of the work that has been undertaken by the U. S. Coast and Geodetic Survey in the form of precise triangulation to show whether the earth's crust in California is stable or is in movement and, if the latter, the rate and the extent of the movement. The triangulation which has already been done and that which is under way during the present year will, in the near future, be supplemented by precise leveling which will show the degree of stability of the earth's surface in the vertical direction.

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It is only by geodetic work of the most precise character that movements of the earth's surface can be detected between seismic disturbances. With the repetition from time to time of the triangulation and leveling in selected areas it will be possible to make a very careful study of surface conditions and movements. With such information available the seismologist will be able to apply quantitative methods which will greatly advance the science.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

THE RESULTS OF THE TRIANGULATION DONE IN CALIFORNIA IN 1922 TO TEST THE STABILITY OF THE EARTH'S SURFACE

O. S. Adams

The redetermination of the positions of triangulation stations made in 1906-07, in the California earthquake region, was based upon the stations at Mt. Diablo, and Mocho, situated some fifty miles east of the San Andreas fault line. Since there was some question whether these points might not have moved with respect to each other, the third determination, also by precise triangulation, of the points in 1922 was made to depend upon Mt. Lola and Round Top, located some 160 or more miles east of the fault line.

The mean of the triangle closures was 0″.76 and the maximum closure was 1″.93. Of the 37 closed triangles, 28 had closures of one second or less. These results show that this triangulation is somewhat better than the usual requirement for precise work. There were thirty-five condition equations in the adjustment with a resulting probable error of an observed direction of ±0″.32.

The difference between the 1922 positions and those of 1906 show a displacement of a little less than four feet in a general southward direction. This is less than one part in 200,000 of the distance from Mt. Lola to Round Top, and in azimuth it represents about one second of twist. A southward displacement would require a combination of length and azimuth discrepancy. The lengths of triangulation, in general, can be depended upon to about one part in 100,000; in a scheme tied together as this is, one second in twist should hardly be expected. However, if the old determination of Mt. Diablo and Mocho should have been affected by an azimuth displacement northward and these 1922 determinations by one southward, the azimuth twist could be less even than a half second which might well be expected.

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	Displacement 1922–1906 Based on Mt. Lola and Round Top		Displacement 1922–1906 Mt. Diablo and Mocho held fixed	
	Lat. ft.	Long. ft.	Lat. ft.	Long. ft.
Mt. Diablo	−3.4	−0.8	....	....
Mocho	−3.5	−2.0	....	....
Ross Mt.	−3.7	+2.8	−0.2	+4.2
Mt. Tamalpais	−3.6	+0.6	−0.1	+2.0
Sierra Morena	−3.5	−0.5	0.0	+0.9
Loma Prieta	−2.0	−2.9	+1.5	−1.5
Lick Observatory, small dome	−3.7	−2.2	−0.2	−0.8
Farrallon L. H.	−4.9	+0.6	−1.4	+2.0
Point Reyes L. H.	−4.6	+0.4	−1.1	+1.8

The minus sign indicates movement to the south and to the east in latitude and longitude, respectively.

U. S. Coast and Geodetic Survey,
Washington, D. C.

MEASUREMENT OF DISTANCE BETWEEN MOUNT WILSON AND SAN ANTONIO PEAK MADE IN CONNECTION WITH THE DETERMINATION OF THE VELOCITY OF LIGHT BY PROFESSOR A. A. MICHELSON

C. V. Hodgson

The work was undertaken in response to a request by Dr. A. A. Michelson that the Coast and Geodetic Survey determine the length of the line, over 20 miles in length, between Mount Wilson and San Antonio Mountain, with an accuracy represented by an actual error of not to exceed 1/250,000. To obtain the length of this line, which extended over very rugged country, it was necessary to measure a base in the valley lying to the south, and to carry the base length by triangulation to the line desired.

Before beginning the field work, the members of the Division of Geodesy of the Survey examined critically the modern methods of base measurement and triangulation. In the triangulation the choice of figure, the probable error of a direction, and the method of determining the differences of elevations of the stations were examined with special care. The figure selected gives the greatest possible strength in the connection between the base and the Michelson line. Field

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methods were adopted which would insure a probable error of a direction of not more than about 0".2 of arc, or about half that obtained in ordinary precise triangulation, and would give the differences of elevation with an error of not more than one foot.

The investigations concerning base measurement were directed principally toward the problem of standards, the accurate measurement of the tension applied to the tape, the probable errors allowable in the grade and alignment corrections, and the general problem of adopting methods of measurement which would minimize the effect of unavoidable small systematic errors.

The location of the base and of the Michelson line made it very difficult to secure the requisite accuracy. The valley in which the base was located was under a high state of cultivation and the base changed in direction so frequently that 19 angle stations were necessary on the base line alone. Moreover, while observing from the base stations to the mountain stations the atmospheric conditions were very unfavorable, as they always are when observing from a valley toward mountains. The field reports, however, indicated a maximum triangle closure of only about 0".7 and an average closure of 0".4 of arc, and it therefore seems probable that the length of the Michelson line will be determined with the desired accuracy.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE DENSITIES OF DEEP-SEATED MATERIAL OF THE EARTH'S CRUST, AS DETERMINED BY CHEMICAL ANALYSIS, AND THE BEARING OF SUCH DENSITIES ON THE THEORY OF ISOSTASY

HENRY S. WASHINGTON

A résumé was given of the work which had been done by the author, showing that the densities of igneous rocks found at different places on the earth's surface, as computed from chemical analyses, bear a very definite relation to the elevation of the ground at which the rocks are found. The higher the elevation of the earth's surface the less is the density of the igneous rocks. This fact fits in well with the theory of isostasy which postulates that under each topographic feature there is a compensating deficiency or excess in density. The investigations in rock densities and isostasy will give information in regard to the earth's crust that apparently cannot be gained by other means.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

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FORCES TENDING TO CAUSE MOVEMENTS IN THE EARTH'S CRUST

W. D. LAMBERT

The title is extremely comprehensive. Of all the numerous manifestations of force in the earth's crust two have been selected for their bearing on the Taylor-Wegener hypothesis of continental migration: (1) a small force tending to move continents towards the equator; (2) a possible way in which the earth's axis of rotation might be displaced in the body of the earth.

Wegener's form of the hypothesis assumes that the continents may be likened to blocks of lighter matter (called "sial") floating on a magmatic substratum (called "sima"). To move these continental blocks there is needed a *selective* force, one which acts on the continents, not as on mere undifferentiated portions of the crust, but which has on the continents an effect different from that which it has on the surrounding magma. There is such a force tending toward the equator and roughly proportional to the height of the continent above the sustaining magma. It is, however, very minute (of the order of 1/1,000,000 of gravity), and is probably ineffective in moving the continental blocks against the resistance of the "sima."

Large displacements in the position of the earth's axis of rotation in the body of the earth play an important part in Wegener's scheme, although they are not a necessary part of a theory of continental migration. Wegener's explanation of these displacements of the axis or pole (taken from a memoir by Schiaparelli) is mechanically unsound. There is, however, a possibility, not considered by Wegener, of explaining fairly large polar displacements.

Since the earth's rotation is being slowed down by tidal friction, the earth in the past had presumably a greater ellipticity and its free period in the variation of latitude (now 14 months) was more nearly one year, which is the period of forced annual oscillation of the pole due to meteorological causes. This near coincidence of periods would produce resonance and the amplitude of the oscillations in latitude would be greatly increased, perhaps so greatly that the earth's crust would be ruptured under the resultant stresses, thereby producing something the same effect as if the earth were fluid, so that a new mean position of the pole might be established. Our equations for the variation of latitude are limited to small oscillations, so that we cannot follow the changes with mathematical rigor.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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SOME PHASES OF THE RESISTANCE OF THE EARTH'S MATERIAL TO CHANGES

C. E. VAN ORSTRAND[1]

The rocks in the crust of the earth are constantly undergoing readjustment as a result of metamorphism, thermal changes, and redistribution of load. Apart from the evidence afforded by shore lines and regions of seismic activity, there is perhaps no well-authenticated evidence of surface movements now in progress. Artificial movements are oftentimes developed in the rocks beneath stone quarries as a result of diminishing the vertical cross section over which the stresses are distributed. It is found in this way that the rocks in certain areas are in a state of ease—practically no strain—while in other areas the stresses approach the elastic limit.

Contrasted with these small displacements are the enormous displacements which have occurred in geological time, some of which are undoubtedly vertical, while in others, the overthrust faults, it appears that large masses have been displaced horizontally over distances of several miles. The Serpent Mound Structure in Adams County, Ohio, and the Bearpaw Mountains, Montana, which are being studied respectively by Professor Walter H. Bucher of the University of Cincinnati, and Mr. Frank Reeves of the United States Geological Survey, are excellent examples of vertical displacement due apparently to gravitational forces. The Lewis overthrust, Montana, is a conspicuous example of horizontal displacement extending over a length of more than 100 miles. Mr. M. R. Campbell, of the United States Geological Survey, estimates the displacement at the southern end of the fault to be about 15 miles. A complete solution of the problem of overthrust faults is perhaps impossible, but it is not improbable that the displacements, following the lines of least resistance, are vertical in the lower portion of the isostatic column, but at or near the top of the column they may be inclined to the vertical, and in extreme cases, may even be horizontal.

The kind of equilibrium acquired by rock masses may be suggested by the after-effect curves of steel tapes. With small loads the curves approach an asymptote parallel to the axis of time, while with larger loads, but not necessarily exceeding the elastic limit, the asymptotes are inclined to the axis of time and there is no approach to a definite state of equilibrium.

Jeffreys' recent evaluation of the thermal contraction of the globe tends to show that cooling alone is more than sufficient to account for the contraction necessary to produce the mountain ranges of the

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continents. An obvious difficulty encountered in the thermal-contraction hypothesis of mountain building is the concentration of practically all of the thermal contraction of the globe in the small areas occupied by the mountain ranges. It is perhaps not unreasonable, therefore, to assume that the chief forces involved in mountain building are gravitational and therefore vertical—while the strains resulting from thermal contraction are released from time to time and play a minor part only in the development of a mountain range.

U. S. Geological Survey,
Washington, D. C.

SOME RECENT PROGRESS IN ISOSTATIC INVESTIGATIONS

WILLIAM BOWIE

The principal progress made in the theory of isostasy during the past year or two has been the recognition given the subject by scientific organizations dealing with the earth.

At the meeting of the Geological Society of America, held at Amherst in December, 1921, there was a symposium on isostasy at which were presented nine papers which dealt with relations between the theory of isostasy and geological phenomena.

At the meeting of the same Society at Ann Arbor in December, 1922, there were presented several papers in which the theory of isostasy was given consideration.

A valuable addition to isostatic literature is "The Strandflat and Isostasy" by Dr. Fridtjof Nansen, which appeared in December, 1922. The author shows that the isostatic balance was maintained almost, if not perfectly, in Norway during the loading and unloading of the area by ice caps and their disappearance, respectively. He uses the physiographic evidence to show that areas studied by him are in very close isostatic equilibrium.

Possibly the greatest progress made in the theory of isostasy during recent times has been the establishment of the fact that gravity anomalies are, to a great extent, due to the effect of local deviations from normal densities in the material of the earth's crust close to the gravity stations. In the United States there are a number of cases where stations very close together have decided differences in their anomalies. These anomalies could not show such a deviation if their cause were a lack of isostatic balance of the portion of the isostatic shell below them, for if the cause were deep-seated the effect on two stations close together would be very nearly the same. It has been shown that gravity stations on the Cenozoic formation have a decided tendency to be negative in sign, and the largest negative

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anomalies in the United States are on that formation. It has also been found that the gravity stations on the pre-Cambrian formation have a tendency to be positive in sign, and the largest positive anomalies in the United States are at stations on that formation.

As a result of showing that the large gravity anomalies are due to the local rather than to regional causes, we are safe in concluding that the earth's crust is more nearly in a state of equilibrium than had been supposed previously.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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SECTION OF SEISMOLOGY

INFORMAL COMMUNICATION OF THE SEISMOLOGICAL WORK OF THE U. S. COAST AND GEODETIC SURVEY

N. H. Heck

The proposed transfer of seismological investigation from the Weather Bureau to the Coast and Geodetic Survey, which was recommended to Congress by the Secretaries of Agriculture and Commerce, was discussed—the reason for the proposed action being given. The opportunity was taken to indicate to the Section of Seismology what this action might result in if approved. It was stated that the various seismologists throughout the country are interested in such a change. The definite program outlined included the following:

1. Establish a first-class seismological station at the Magnetic Observatory at Tucson, Arizona, without an increase of personnel at the present. The value of such a station near but not in the California earthquake region was pointed out.

2. Further development would include a similar program at Sitka, Alaska and Porto Rico. At Honolulu a new building and an instrument for measuring the vertical component would meet the needs.

3. Discussion of the further possibilities for the Continental United States was deferred.

It was pointed out that if this program resulted in the establishment of only one first-class seismological station, the effort would be worth while. The need for the assignment of one full-time mathematical physicist for interpretation work was indicated as essential to such a program.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE SEISMOGRAPH AND FRICTION

Harry Fielding Reid

The friction at the marking point of seismographs recording on smoked paper has always been a difficulty. The direction of the frictional force is always changing. The elementary theory in which the friction is considered a constant force and at right angles to the lever has proved unsatisfactory. Galitzin attempted to improve it by assuming that the friction is a constant plus term proportional to the first and the second powers of the velocity, but he neglected the variation in the direction.

Direct experiments show that the friction is practically a constant, and that it is necessary to take account of its varying direction.

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When the seismograph is recording a simple harmonic movement the direction of the movement varies harmonically; it can therefore be represented by a Fourier's series, in which the coefficients can be determined. Mathematical analysis shows that a very close approximation to the true effect can be obtained by neglecting all terms of the series except the first. The general equation of the seismograph can then be solved and the magnification of the earth movement determined. The formula obtained is similar to the known formula for the magnification of harmonic movements, except that it contains an additional term to take account of the friction. This term can readily be determined; and a series of tables makes it possible quickly to find the true magnification to a very close degree of approximation.

Johns Hopkins University,
Baltimore, Maryland.

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SECTION OF METEOROLOGY

AN EXAMINATION OF THE DUST CONTENT OF THE ATMOSPHERE

HERBERT H. KIMBALL

At the Rome meetings of the International Geodetic and Geophysical Union in May, 1922, Sir Napier Shaw, President of the Meteorological Section, proposed the purchase of twelve Owen's Dust Counters for distribution to observatories in different countries affiliated with the Union, to be used in an international study of the dust content of the atmosphere.

The importance of this study is apparent from the close relation known to exist between atmospheric dustiness and visibility. Since visibility is one of the most important meteorological factors in aviation, an accurate forecast of this phase of the weather is desirable. Hence, the importance of accurate data on atmospheric dustiness.

Also, at intervals, volcanic eruptions throw vast quantities of dust high into the atmosphere, where it may float for months or even years, covering perhaps an entire hemisphere, and diminishing the intensity of incoming solar radiation. Also, it is suspected that at times dust of cosmical origin finds its way into our atmosphere. The adequate study of these questions demands international co-operation.

One of the twelve dust counters distributed as proposed above was received by the U. S. Weather Bureau, and since December 7, 1922, a count of the number of dust particles contained in a cubic centimeter of air has been made at Washington on each working day, generally at the American University, D. C., in a suburb about 3 miles northwest of the city, but sometimes at the base and top of the Washington monument, which is in a smoky section of the city.

The number of dust particles has been found to vary from about 100 to 4,000 per cubic centimeter.

With the minimum number of dust particles the Blue Ridge Mountains in Virginia, 50 miles distant, are clearly visible. With the maximum number of particles the visibility is ½ mile or less, depending upon the humidity of the atmosphere.

Dust counts have been made on two occasions during aeroplane flights. The first of these was to a height of 12,000 feet. The number of dust particles per cubic centimeter increased from a minimum of 499 at the surface to a maximum of 1,716 at a height of 9,000 feet, and fell off to 1,357 at 12,000 feet. On the second flight the number of particles per cubic centimeter was 678 at the surface, 1,741 at 3,000

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feet, and 158 at 6,000 feet, which was at the base of a cloud layer from which rain commenced to fall shortly afterwards.

On the first flight there appeared to be a relation between air movements at different levels and dustiness.

While attended with difficulties, the feasibility and utility of dust counting from aeroplanes appears to be established. Further development of this line of work is expected.

U. S. Weather Bureau,
Washington, D. C.

THE METEOROLOGICAL WORK ON THE *JACQUES CARTIER*

E. H. Bowie

The *S. S. Jacques Cartier,* a freighter of 19,300 tons owned by the Compagnie Generale Transatlantique, in addition to functioning as a freighter, serves as a training school for prospective officers of the merchant marine.

Through the co-operation of the National Meteorological Service of France (Office Nationale Meteorologique) the *Jacques Cartier* has also been employed to test the practicability of maintaining a floating weather service for the collection of meteorological observations by radio, the issue of weather forecasts and warnings for the guidance of vessels navigating the oceans. Supervising Forecaster Edward H. Bowie of the Weather Bureau, on the invitation of the Compagnie Generale Transatlantique, extended through Captain Coyecque, professor and meteorologist of the Training School, made the voyage, New Orleans to Le Havre, February 11 to March 2, 1923, and returning from Boulogne to Santa Cruz del Sur March 13-30, 1923.

In charting the meteorological observations received on board the vessel main dependence was had on the observations broadcast from Arlington and the Eiffel Tower there being no time on either the outward or the inward voyage when the vessel was not in communication with one or both of these stations. The remarkable fact remains that it is possible at times for a vessel at sea to receive observations from Constantinople on the east to the Pacific coast on the west.

A single example of the weather information broadcast by the *Jacques Cartier* will convey an excellent idea of the scope of the meteorological activities of the vessel. The example follows:

BROADCAST—MARCH 20TH—GREENWICH NOON

Meteo. Jacques Cartier to all ships: North Atlantic weather situation March 20th, Greenwich noon. Pressure is high over northwestern Europe; 30.36 also from Bermuda to Azores and northward also over American Atlantic States. Trough of low pressure extending from Iceland (29.60) southeastward to Gibraltar

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(29.50). Disturbance of great intensity (29.00) over Newfoundland moving east-northeastward.

Forecasts: Track, Azores to Gibraltar—unsettled weather eastern portion—northerly fresh winds, squally weather and overcast weather western portion. Stop. Tracks, Azores to English Channel—overcast weather and moderate easterly winds eastern portion—fresh or strong northerly winds and squally weather western portion. Stop. Azores region—fresh northerly winds moderating today and shifting to southeast and south tomorrow—overcast weather becoming fair. Track—Azores to Bermuda—Moderating northerly winds and fair weather between longitudes 30° and 42°. Southerly increasing winds shifting to southwest west of 42°, weather becoming overcast and probably rainy.

Advisory for westbound ships over transatlantic tracks west of Ireland to south of Grand Banks: Disturbance of great intensity (29.00) over Newfoundland moving toward Iceland will be attended by strong shifting winds today and tonight between longitudes 35° and 55° followed by fresh or strong northerly winds. Winds will shift tomorrow morning between 40° and 50°.

U. S. Weather Bureau,
Washington, D. C.

INDIAN SUMMER AS A CHARACTERISTIC WEATHER TYPE OF THE EASTERN UNITED STATES

ROBERT DE C. WARD

The author's studies of the weather maps which characterize Indian Summer weather have led him to recognize a type of pressure distribution which uniformly gives several days of weather commonly called Indian Summer. This pressure distribution was described as a more or less stagnant area of high pressure over the southeastern States and a weak cyclonic area passing slowly down the Saint Lawrence Valley. The resulting winds are light, and the moderate chill of the early morning and evening resulting from a fairly well marked diurnal range of temperature is swept away by the genial warmth of the light southerly winds, and by the strong isolation of the daytime.

He also emphasized the fact that the Indian Summer pressure type can and does occur in all seasons, but that the lack of precipitation, the prevailing haziness, and the temporary stagnation of the general atmospheric circulation are features most fully developed in autumn.

Harvard University,
Cambridge, Massachusetts.

TEMPERATURE INVERSIONS IN THE FREE AIR

W. J. HUMPHREYS

It is well known that a temperature inversion, that is, an increase of temperature with increase of elevation for a short distance, often occurs at the upper surface of a stratus cloud. Also that a similar

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inversion is frequently found at about the same height when there are no clouds.

Some, perhaps all, of these inversions, especially those that occur on cloudless days, are caused, as Sir Napier Shaw has explained, by the turbulence of the lower air incident to winds. This stirring up of the lower air tends to bring it all to an equipotential temperature, hence to warm the under portion of the agitated layer and to cool the upper portion.

The less pronounced inversions in the higher portions of the atmosphere occur at boundaries between layers of wind that differ more or less in speed or direction, or, nearly always, both. In these cases turbulence, so far as it exists, warms, as explained above, the under portion of the agitated layer, and produces a temperature inversion, or, at least, a decrease in the temperature lapse with increase of elevation, at its upper surface.

However, since layers of air of different density glide over each other without rapid intermingling, it follows that the higher and less pronounced inversions of the free air are owing, chiefly, to the different origins of the winds immediately above and below them.

U. S. Weather Bureau,
Washington, D. C.

THE WIND FACTOR IN FLIGHT: AN ANALYSIS OF ONE YEAR'S RECORD OF THE AIR MAIL[1]

WILLIS RAY GREGG and LIEUT. J. PARKER VAN ZANDT

From an analysis of one year's records of the Air Mail Service between New York and San Francisco it has been found that at the average altitude of flight, about 1,500 feet above the ground, allowance must be made for a wind of 7 miles per hour from the west. In other words, westward flights will, on the average, be made at a speed of 14 miles per hour less than will eastward flights. A more detailed study of the New York to Chicago part of the route gives almost exactly the same wind factor as for the entire trans-continental route. This value of the wind factor has been verified by an examination of 8,667 free air observations with kites and pilot balloons, and the agreement is remarkably close. The importance of this agreement lies in the fact that, in fixing flight schedules in other regions or at other altitudes, dependence can be placed upon *either* method in case only one is available.

[1] Paper presented at Washington, D. C., before the American Meteorological Society on April 16, 1923, and the American Geophysical Union, Section (c) Meteorology, on April 18, 1923.

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From a further study of the data, schedules that can be guaranteed 90% of the time have been determined for aircraft of any cruising speed between 50 and 150 miles per hour. In making up these schedules allowance has been made for head winds of 36 miles per hour or more in westward flight and 20 miles per hour or more in eastward flight, these being the wind speeds that are shown by kite and balloon records to occur 5% of the time. When they do occur, the flights will be somewhat delayed, but nevertheless completed. During the remaining 5% of the time flights are likely to fail altogether or be seriously delayed because of exceptionally unfavorable weather, such as severe rain or snow storms, poor visibility, etc.

Finally, a general wind curve has been prepared by means of which various schedules based on other percentage performances, greater or less than 90% and for different lengths of routes, may be determined. With the normal and high cruising speeds known quantities, allowance is made for an adverse wind such that the flight can be made in any desired time. The percentage frequency of this adverse wind is then read from the curve and thus is determined the percentage of the time that the desired schedule can be guaranteed.

U. S. Weather Bureau (Gregg),
Washington, D. C.
U. S. Air Service (Van Zandt),
San Diego, California.

PROGRESSIVE CHANGES IN THE FIELD OF METEOROLOGICAL OBSERVATIONS OF THE U. S. WEATHER BUREAU

A. J. Henry

Two maps were shown. The first portrayed the distribution of stations reporting by telegraph to the Central Office of the Signal Service in Washington, D. C., at the end of the first year of operation as a Federal Weather Service. The number of stations was 55. The second map showed the location of stations reporting to the Weather Bureau at the present time both by the electric telegraph and cable lines and by radio transmission from ships at sea. The number of stations reporting at the present is 332 distributed over widely separated parts of the globe. The Asiatic coast and the Philippines in the Far East, the Islands of the Pacific, Alaska and the West Indies are some of the regions from whence reports are received.

U. S. Weather Bureau,
Washington, D. C.

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SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

REPORT OF THE COMMITTEE ON ATMOSPHERIC-ELECTRIC PHENOMENA AND MEASUREMENTS IN THE TROPOSPHERE AND STRATOSPHERE[1]

W. F. G. Swann, *Chairman*

Last year I reported that three members of the committee had undertaken the preparation of reports, Dr. Austin having promised a report on Wireless Strays, Dr. Blair a report on Instrumental Technique pertaining to upper air investigation, and Dr. Mauchly a report on the Diurnal Variations of the Atmospheric Electric Elements. Dr. Humphreys, to whom we already owe much of our knowledge concerning thunderstorms, promised to look into the question again at this stage, and see whether the time was ripe for a further report. He has concluded that the amount of new material which is not already summarized in existing reports is not sufficient to warrant the preparation of a further account at this time.

Dr. Austin has tendered his report, and has enriched our knowledge of the field by the publication of several papers on the subject of wireless strays and allied phenomena. Dr. Mauchly has also completed a valuable report on the Diurnal Variation of the Atmospheric Potential-Gradient.

In addition to the foregoing, individual members of the committee and those working in their laboratories have been independently active in investigations pertaining to the fields of our interests. It is perhaps unnecessary to give a detailed list of publications, but will suffice to say that the activities in question have comprised investigations on the Penetrating Radiation with special reference to work at high altitudes, on the Variation of Residual Ionization in Gases with Pressure, on the Nature of Ionic Recombination in the Atmosphere, on the Theory of Ionization by Rapidly Moving Particles, on the Action of the Heavisidean Layer, on Wireless Strays and Allied Phenomena, on the Diurnal Variation of the Potential Gradient, and on certain instrumental matters, for example, two investigations pertaining to the Ebert Ion-Counter. On all of these topics papers have appeared, have been presented at learned societies, or are in process of publication.

[1] Presented at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923. Members of the Committee: L. W. Austin, W. R. Blair, W. J. Humphreys, S. J. Mauchly, R. A. Millikan, and W. F. G. Swann, chairman.

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Last year certain tentative plans of a certain group of scientists for an Algæ Survey were brought to the attention of the Committee, and the opportunity for the prosecution of atmospheric electric observations was pointed out. The committee took cognizance of this information, and the section passed resolutions in sympathy with the project, promising more active co-operation at such time as plans had been more definitely formed by the organization. A letter has been received from one of the members of the organization, the purport of which is to the effect that the plans are temporarily in abeyance pending the consummation of a plan for financing the undertaking. The outcome is expected to be known in a very short time, but until that time no further action can of course be taken by the committee.

With regard to the Committee's plan for initiating the prosecution of atmospheric electric observations at such educational institutions as would be willing to undertake such work, I may say that a beginning has been made at the University of Minnesota, where Professor Zeleny has undertaken to pursue such work, and is making a beginning by installing a potential-gradient apparatus.

University of Minnesota,
Minneapolis, Minn.

REPORT OF THE COMMITTEE ON EARTH CURRENTS AND POLAR LIGHTS[1]

S. J. Mauchly, *Chairman*

The resumption, in February 1922, of earth-current registrations on both the N-S and E-W lines of the Ebro Observatory at Tortosa, Spain, following an interruption of several months, is considered most fortunate. While the need for the recent repairs and replacements is regretted, it is hoped that the changes made will not materially affect the value of the records when these are considered as additions to what is already the longest available series of continuous earth-current registrations. The resumption of registration is especially fortunate, also, because of the opportunity which it will afford for comparative study of the Ebro results with those soon to be obtained at the Watheroo Magnetic Observatory.

The Department of Terrestrial Magnetism of the Carnegie Institution of Washington has well under way the completion of its pre-

[1] Presented at the annual meeting of the Section of Terrestrial Magnetism and Atmospheric Electricity of the American Geophysical Union, Washington, April 18, 1923. Members of Committee: J. H. Dellinger, N. H. Heck, A. J. Henry, A. G. McAdie, S. J. Mauchly, chairman, and W. E. Parker.

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liminary earth-current installation at Watheroo, Western Australia. The initial N-S and E-W lines for this installation are each 2 miles (3.2 km.) long and will constitute the only special installation for earth-current registration in the Southern Hemisphere. However, much interest attaches to the new installation apart from its geographic position and its availability as a comparison station. Briefly stated these additional features are as follows: (1) use of a multiple-point recording potentiometer as recording instrument; (2) automatic comparison of results from 1-mile (1.6 km.) and 2-mile (3.2 km.) lines, respectively, on both N-S and E-W lines; (3) comparison of results obtained by the use of overhead lines with those obtained from underground cables laid in insulating conduit. In addition, it is planned to make a resistivity survey of the entire region occupied by the system for each of the two seasons which differ most regarding the moisture and temperature of the soil, and to devote considerable attention to a study of the characteristics of several types of electrodes as regards suitability for continuous earth-current registration. The progress, to date, of the work on this installation makes it appear very probable that registration will be under way by the end of 1923.

As a result of the work of the MacMillan Baffin Land Expedition of 1921-22 there is now available a record of the aurorae observed from November 1921 to June 1922 at Bowdoin Harbor (64°4 N, 78°0 W) which was Dr. MacMillan's winter quarters. An auroral log is also being kept at Sitka, Alaska, by Mr. F. P. Ulrich, observer in charge at the Sitka Magnetic Observatory of the United States Coast and Geodetic Survey. Since aurorae are also being observed by the "Maud Expedition," under Captain Amundsen, the observations of Mr. Ulrich may prove to be of unusual value in conjunction with those from other stations co-operating with the Expedition.[3]

Some interest has been aroused in the possibility of a connection between aurorae and the phenomena of radio communication by the fact that the failure of a recent attempt to relay a radio message across Canada was accompanied by aurorae. It has been suggested by the Committee that interested radio operators who are suitably stationed could probably obtain valuable data which might be of assistance in determining the nature and magnitude of any interrelation which may exist between the two phenomena. For example, without going into the details of procedure, two co-operating observers, far apart along an approximate east and west line, could readily deter-

[3] At the time this report was prepared for publication Dr. MacMillan had completed preparations for an expedition to the Arctic regions in 1923-24, with an observational program including auroral observations similar to those made in 1921-22.

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mine the existence of any effect upon communication between their stations and the nature and intensity of such effects. Precisely analogous remarks would apply to two observers separated by a great north-south distance. It is of course presumed that, of each pair of co-operative radio observers, at least one is at a sending station, and at least one in a region of high auroral frequency; also that stated periods of simultaneous recording of both radio and auroral conditions have been agreed upon by the observers. From a study of the data from several series of such co-operative observations, especially if they cover simultaneous observations during aurorae, for both the E-W and N-S directions, it should be possible to draw certain preliminary conclusions of value both from the view-point of radio communication and as regards indirect evidence concerning the ionization of the upper regions of the atmosphere during aurorae. [The foregoing ideas will be carried out, so far as possible, during the ensuing year, through the use of a specially prepared form by radio stations in Canada relaying radio messages to and from the MacMillan Arctic Expedition, 1923-24.]

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

PROGRESS REPORT OF THE COMMITTEE ON RELATIONS BETWEEN TERRESTRIAL MAGNETISM, TERRESTRIAL ELECTRICITY, AND SOLAR ACTIVITY[1]

LOUIS A. BAUER, *Chairman*

Measures of Solar, Magnetic, and Electric Activity.—The compilation and computation of measures of solar activity, magnetic activity, and electric activity, based on all available data, have been continued by the Department of Terrestrial Magnetism. Thanks to the co-operation of Professor Wolfer of Zürich, we are promptly supplied with his relative sun-spot numbers, which are published as soon as possible in the *Journal of Terrestrial Magnetism and Atmospheric Electricity* in order to make the data available to others. We have at present the final sun-spot numbers through 1918 and the provisional ones complete from 1919 to March 1923, inclusive. From these data, it appears that for the present cycle, the minimum sun-spot activity occurred in 1913, and an extraordinarily large maximum (103.9 for

[1] Presented at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923. Members of Committee: C. G. Abbot, Louis A. Bauer, chairman; R. L. Faris, George E. Hale, and C. F. Marvin.

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the mean of the year) in 1917; it is not yet possible to say whether the minimum has again been reached. The mean number for 1922 was 14.7, and the mean monthly numbers for January to March 1923 are, respectively: 5.3, 1.6, and 4.0. There has been no such high maximum as that of 1917 since 1870, when the mean number for the year was 139.1. For the first time since 1871 has the monthly mean number exceeded 150, as it did in August 1917, viz, 154.5.

An important publication during the year has been that by Hale on *"Invisible Sun-spots."*[2] At the Rome 1922 meeting of the International Astronomical Union, various committees on solar phenomena were combined into one under Hale's chairmanship; there are 21 widely-distributed members, among whom, of our Union, are Hale, Abbot, and Bauer.

Abbot has reported to the Committee the general results of the *solar-radiation observations*, October 1920 to September 1922, made at the two stations of the Smithsonian Institution, Harqua Hala, Arizona, and Montezuma, Chile. He calls attention to the high solar-constant values until 1922, usually exceeding the normal value of about 1.94 calories. Nothing so marked as the change in 1922 to low values has occurred since the observations were begun at Mount Wilson in 1905. (Dr. Abbot also personally presented his report at the meeting of the Section; it will be found published, in expanded form, in the *Monthly Weather Review* for February 1923, pp. 71-81.)

Marvin reports continuation of the attempts to find *relationships between meteorology and solar activity*. An outline of this work was presented by him at the meeting of the American Meteorological Society at Washington, on April 16, 1923.

Bauer has continued the disclosing of *relationships between terrestrial magnetism, terrestrial electricity, and solar activity*. The twelve-year series of observations at the Observatorio del Ebro, Tortosa, Spain, 1910-1921, pertaining to earth currents, atmospheric electricity, and terrestrial magnetism, have been subjected to discussion and analysis, as also the available atmospheric-electric data at other observatories. The following general conclusions[3] are drawn:

1. The relationship between sun-spot activity and atmospheric electricity turns out to be, for locally undisturbed stations, as definite as in the case of terrestrial magnetism; the sun-spot influence on the periodic variations of the atmospheric potential-gradient is, in general, as great as on the periodic variations of terrestrial magnetism; and as concerns the effects on the absolute values, the sun-spot

[2] *Proc. Nat. Acad. Sciences*, July 1922, pp. 168–170; see also abstract in the *Year Book of the Carnegie Institution of Washington* for 1922, p. 212.

[3] See *Terr. Mag.*, vol. 27, 1922, p. 30.

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influence is about 300 times greater in atmospheric electricity than in terrestrial magnetism. The potential gradient of atmospheric electricity, and, presumably, the Earth's total negative electric charge, is furthermore subject to an annual or secular change, which may vary in magnitude and sign from one sun-spot cycle to another.

2. The potential gradients of earth currents, as recorded at the Ebro Observatory, 1910–1920, varied during the sun-spot cycle, decreasing in the direction of normal flow of current with increased sun-spot activity; the diurnal range, however, increased with increased sun-spot activity.

3. There is evidence of a similar six-hour wave in atmospheric electricity, earth currents, and terrestrial magnetism.

The bearing of conclusion 1 on the question of the origin and maintenance of the Earth's electric charge needs no elaboration here.

The interesting six-hour wave referred to in the third conclusion, the amplitude of which increases with increased solar activity, just as does that of the 24-hour wave, has received further attention. The Fourier analysis of the potential gradient of atmospheric electricity has been made in the Department of Terrestrial Magnetism for each month of the mean year of the 11-year series for the Ebro Observatory. Once more the six-hour wave is found to be of peculiar interest. For every month of the mean year, excepting November, December, and January, its amplitude is larger than that of the eight-hour wave, and on the average for the year the amplitude is about one-third that of the 24-hour wave and nearly half that of the 12-hour wave. Its phase angle, relatively, shows the same constancy within less than half-hour, during the year, as does the 12-hour wave. It is not possible to enter into further details, but my colleague, Mr. Mauchly, will also have something interesting to report in his paper regarding a six-hour wave. Unfortunately previous analyses have frequently stopped with the third term, and it was assumed that the series would thereafter converge. The flaring up of the amplitude of the fourth wave, even at such an exceptionally favorably located station as is the Observatorio del Ebro, is a matter of considerable interest.

Another feature of interest is the double wave shown by the annual variation in the diurnal variation of the potential gradient, as disclosed by the combined amplitude, as well as by the amplitudes of the 12-hour and the 6-hour waves separately. The maximum amplitudes occur near the equinoctial months, the minimum near the solstitial months. Striking similarities in the annual variation of the following phenomena have now been shown to subsist: Magnetic disturbances, earth-current disturbances, polar-light frequencies, atmospheric-electric disturbances, and the earth-effect on solar activity.

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Even the lag in the second maximum, occurring in October instead of September, is shown by all phenomena.[4]

The annual variation of other geophysical quantities has likewise required attention in the pursuit of the relations sought for by the Committee. For example, the annual variation of the potential gradient of atmospheric electricity, as observed at stations distributed over the Earth from the Arctic to the Antarctic regions, shows phenomena similar to those resulting from a system of vertical electric currents caused by the translatory motion of an electrically-charged sphere through the ether, for example, by the charged Earth during its orbital motion about the Sun; this hypothesis is being further investigated. The available data reveal the following types:

Type *a*. From the Arctic regions to about parallel 33° North and from about 40° South to the Antarctic regions, the maximum potential gradient occurs near the December solstice and the minimum near the June solstice.

Type *b*. In the region from about 33° North to 40° South, or over about half of the Earth's surface in the lower latitudes, some of the stations show a reversed annual variation to that of type *a*, hence, maximum potential gradient near June solstice and minimum near December solstice.

Type *c*. In region for *b*, or between *a* and *b*, there are certain stations showing a mixed type of *a* and *b*.

On the average, from the Arctic to the Antarctic, the annual range of the potential gradient is about 60 per cent of the average potential gradient for the year; the data in the North Hemisphere seemingly indicate that the range decreases as the region for type *b* is approached. There are some indications that the bounding parallels between regions of types *a* and *b* may be found to be magnetic parallels, rather than geographic ones.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

REPORT OF THE COMMITTEE ON MAGNETIC STANDARDS, AND INSTRUMENTS AND METHODS OF AERIAL MAGNETIC MEASUREMENTS[1]

J. A. Fleming, *Chairman*

Comparisons of magnetic and electric methods for determining the horizontal intensity of the Earth's magnetic field.—With respect to

[4] See *Terr. Mag.*, vol. 26, 1921, pp. 113–115, vol. 27, 1922, p. 27.

[1] Presented at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923. Members of Committee: C. G. Abbot, J. P. Ault, S. J. Barnett, L. J. Briggs, J. A. Fleming, chairman, and N. H. Heck. The Committee carried on its duties by correspondence, and the report was compiled largely from sub-reports submitted by Messrs. Ault, Briggs, Fleming, and Heck.

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magnetic standards, the outstanding work during the year was the completion of an indirect comparison between three electro-magnetic instruments for determining the horizontal intensity of the Earth's magnetic field, viz, the Schuster-Smith magnetometer of England, the Watanabe electric magnetometer of Japan, and the Carnegie Institution of Washington sine galvanometer designed by Dr. Barnett and constructed by the Department of Terrestrial Magnetism. These comparisons were obtained by Messrs. Parkinson and Brown of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington using standard magnetometers of the Department for the comparisons at the National Physical Laboratory, Teddington, England, and at the magnetic observatory, Kakioka, Japan; the magnetometers were later carefully compared with the sine galvanometer at Washington. The results show that the Schuster-Smith magnetometer and the sine galvanometer give values differing by less than 1/10,000 part of the value of the horizontal intensity, H, of the Earth's magnetic field, or less. The Watanabe instrument, however, for some reason indicates values greater by 1/3,000 part of H, but field instruments were used for this work and there is somewhat greater uncertainty in the result than for the other comparisons.

The provisional international magnetic standard for H adopted in 1914 by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, as based on all available data respecting the results of inter-comparisons of magnetic instruments made the world over by various organizations and the Department, was found from extensive comparisons made at Washington, D. C., in June and August 1921 and again in February and March 1923 to be in practical agreement with the sine galvanometer. Thus it is found that the provisional H-standard gives results agreeing within 1/5,000 part of H or less with those from electro-magnetic methods (excluding Japan), and hence is well within the limit of error for all practical and theoretical requirements.

Dr. Chree reports that the comparisons of his standard magnetometer with the Schuster-Smith magnetometer also show substantial agreement between the magnetic and electric instruments.

Maintenance of standards provisionally adopted by the Department of Terrestrial Magnetism.—The results of comparisons at Washington between the standard magnetometer and earth inductor and magnetic instruments of various designs, as well as the comparisons with the electric instrument referred to above, show a satisfactory maintenance of the standards well within the limits of error of observation. The compilations of results again show that for the desired precision it is necessary to exercise close control on the magnetometer

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constants, and particularly on changes in the moment of inertia of the oscillating magnet and its suspension and on possible changes in the distribution factors for the magnet systems used.

Comparisons of magnetic standards at observatories.—Comparisons of magnetic standards have been made by the Department of Terrestrial Magnetism, since the last report of the Committee, at 14 observatories in France, England, Scotland, Denmark, Finland, Germany, Holland, Belgium, Spain, Portugal, Algeria, Egypt, Japan, and Australia. Mr. W. C. Parkinson of the staff of the Department of Terrestrial Magnetism made the comparisons at 12 of these observatories, while. Messrs. F. C. Brown and D. G. Coleman of the Department secured the comparisons in Japan and Australia. The results indicate again the necessity of frequent control comparisons, with well-determined standards, for all observatories. It is particularly emphasized, as a result of these comparisons, that the earth inductor should replace the dip circle for the determination of magnetic inclination.

Magnetic standards of the United States Coast and Geodetic Survey.—Since the establishment of the Cheltenham magnetic observatory the regular absolute instruments of that observatory have been regarded as the standard instruments of the U. S. Coast and Geodetic Survey and all other absolute instruments of the Bureau have been referred to them either directly or indirectly. In the case of field instruments, direct comparisons are usually made at the beginning and end of each field season; in the case of the instruments at other observatories, direct comparisons have been made at every opportunity, as when an instrument is sent to the office for repairs, but main dependence is placed on indirect comparisons through field instruments.

Comparisons at Cheltenham with instruments of the Department of Terrestrial Magnetism showed that the Cheltenham instruments gave results in substantial agreement with the provisionally adopted international magnetic standards of that Department, so far as dip and declination were concerned, but that for horizontal intensity the results were too great by about one part in one thousand. The same thing was indicated by the average of the various field magnetometers of the Coast and Geodetic Survey. Accordingly it was decided, beginning with 1913, to adopt as the standard for horizontal intensity the results with magnetometer No. 26 at Cheltenham diminished by 1 part in 1,000.

The constancy of this H-standard has been controlled by repeated comparisons with other magnetometers, in particular magnetometer No. 40, an India Survey pattern instrument held in reserve as a spare observatory magnetometer.

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In 1918 this spare magnetometer was compared with the standard magnetometer of the Department of Terrestrial Magnetism and was then sent for comparison to the Tucson, Honolulu, and Sitka observatories, and returned for another comparison at Cheltenham in 1921. In 1922 a magnetometer of the Carnegie Institution type was compared successively at Cheltenham, Sitka, Tucson, and Cheltenham.

As regards dip, a spare earth inductor has not heretofore been available for indirect comparison between the one at Cheltenham and those at the other observatories, but one is expected from the maker shortly. However, direct comparisons were made in 1922 with the instruments from Porto Rico and Tucson when they were sent to the office for repairs.

Additional control of the instruments at the Honolulu observatory was obtained through comparison with the instruments of the *Carnegie* in 1921.

These various comparisons indicate a satisfactory constancy of the observatory instruments in recent years, but it is not safe to assume that such a condition will continue indefinitely. The same remark applies with greater force to field instruments, which are subjected to more variable and less favorable working conditions.

Horizontal intensity is the element for which the instrumental constants are most likely to undergo change; of these the moment of inertia and the distribution factors require most attention. The apparent variation of the distribution factor from month to month and from year to year deserves careful study.

Development of instruments and methods for aerial measurements. —At the Bureau of Standards considerable work has been done in the development of an Earth-Inductor Compass, designed especially for use in airplanes. The instrument differs from previous compasses of this type in the following particulars:

(1) It employs a null method for its indications, and hence possesses the advantage of sensitivity characteristic of null methods as a class.

(2) An iron core is used in the earth inductor to reduce the size of the instrument.

(3) A method of distant electrical control is used, enabling the earth inductor itself to be located as remotely as necessary to avoid disturbances from magnetic material.

(4) Rolling and pitching errors are eliminated.

The armature is cross-shaped with long thin cores to reduce as much as possible the self-demagnetizing effect. The cores are made of 3½ per cent silicon steel with a length 20 times their diameter. The winding is of the usual closed coil pattern. The shaft of the armature is kept in a vertical position by supporting it from gimbal rings. The

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bearings of these rings are frictionally damped and the armature is weighted. By this means a good rolling and pitching compensation is obtained. The armature is wind driven, using cup-shaped vanes, the connection being made through a flexible shaft. The instrument may be located in the rear part of the fuselage away from the local magnetic disturbances of the engine.

Two sets of brushes of 90 degrees take off current from a 4-section commutator. A closed potentiometer circuit is provided in the form of a square and the 4 brushes are connected to the 4 corners of this square. Two wiping contacts 180 degrees apart draw current from the square frame and are connected to the galvanometer. These wiping contacts are controlled by a dial mounted coaxially with the frame and carrying compass graduations. A position of the dial can always be found in which the galvanometer current is zero, and there is a one-to-one correspondence between this neutral position of the dial and the angle of orientation of the aircraft. A square resistance frame is used to avoid a non-uniformly graduated dial which would result from a circular frame.

It has been found practicable to use this compass in the air for an accuracy of perhaps 2 or 3 degrees.[2]

Attempts have been made at the Bureau of Standards to use an especially devised dip needle in the air with the idea of determining the latitude of the aircraft approximately through reference to charts of magnetic dip. These attempts have proved unsuccessful owing to the peculiar effects of the vibration of the aircraft on the motion of the dip needle. The subject is, however, still under investigation. An earth inductor for determining dip has been constructed and is now under test. The level base of reference in this instrument is a bubble.

One of the chief efforts of Army and Navy Aviation experimenters during the past year has been to try to improve the magnetic compass. Several officers from these Departments have visited the Department of Terrestrial Magnetism and have been given such assistance as was possible to further their efforts in this direction. The attitude of practical aviators seems to be to demand a better compass, and some have felt that if the compass could be depended upon for 90 per cent of the time, all other instruments could be thrown overboard.

Dirigibles would seem to be the better adapted for aerial magnetic work than airplanes on account of their longer cruising radius, convenience for mounting observing outfits, greater stability, etc. The problem of supplying a non-inflammable gas is not yet solved. Helium is too expensive as yet for general use and is regarded as not necessary

[2] A full description of the instrument may be found in *Proc. Am. Phil. Soc.*, vol. 61, No. 1, 1922.

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for commercial use. As an extra safeguard against fire, the all-metal airship is strongly recommended. The all-metal envelope is a protection against static electricity. If a hole is torn in this envelope and the gas catches fire, it will burn as a jet without exploding the airship if the hole does not enlarge. If all-metal airships become the rule, the mounting of magnetic measuring instruments would be complicated unless special metals are used in the construction of certain parts of the airship.

The present tendency in the development of aerial navigation instruments is to emphasize the need of perfecting the radio compass and direction-finder instead of magnetic instruments.

The Loth magnetic cable is being successfully developed to guide an airship from point to point, and in case of landing in a fog the cable is used to guide the aviator to the landing field.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

REPORT OF THE COMMITTEE ON RELATIONS BETWEEN LOCAL MAGNETIC DISTURBANCES, GRAVITY ANOMALIES, AND GEOLOGICAL FORMATIONS[1]

D. L. HAZARD, *Chairman*

During the past year considerable time has been devoted to the study of the relation between local magnetic disturbances and geological formations by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and the U. S. Coast and Geodetic Survey.

The months of July, August, and September were spent by Mr. H. W. Fisk of the Department of Terrestrial Magnetism and his assistant, Mr. J. T. Howard, in Bermuda, where a special study of the magnetic disturbance there was made.

Observations at five primary stations of 1907 show that the secular change between 1907 and 1922 is sensibly the same at all stations as regards horizontal intensity and dip. In declination there is evidence of a sensible difference in different regions.

Diurnal-variation observations carried out simultaneously at two stations in regions of maximum and minimum values of each element indicate that the diurnal variation in horizontal intensity is not affected by the anomaly to a degree measurable by available field methods.

[1] Presented at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923. Members of Committee: D. L. Hazard, chairman; N. M. Fenneman, G. W. Littlehales, and W. J. Peters.

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The diurnal-variation curves for declination where this element has widely different values appear to be identical, but for points where the horizontal intensity has widely differing values there is evidence of a slight difference.

Observations were made at over 100 secondary stations and in greater detail in regions of special interest from which it is concluded that the disturbance may be separated into two parts: (*a*) The primary disturbance affecting large areas, connected with the underlying volcanic structure. (*b*) The secondary disturbance affecting very limited areas, apparently arising from magnetic properties of the soil of varying thicknesses. The intermediate coral limestone was found to be not magnetic.

At the request of Mr. W. R. Crane, Superintendent of the Southern Experiment Station of the Bureau of Mines, an investigation was undertaken by the U. S. Coast and Geodetic Survey during the summer of 1922 to determine whether deposits of non-magnetic iron ore could be detected by means of magnetic observations. Some observations which Mr. Crane had made indicated the possibility that such a method might be used with success, and it was considered worth while to test it by using a more sensitive instrument and more refined methods.

The investigation was carried out in Alabama, the observations comprising three parts: (1) Observations in the brown iron ore district, about 30 miles southwest of Birmingham. (2) Observations at Red Mountain Gap, just outside of Birmingham. (3) Detailed observations near a large specimen of brown iron ore (limonite) and a large specimen of red iron ore (hematite) on the grounds of the University of Alabama at Tuscaloosa.

The owners of the brown iron ore property kindly furnished data regarding the underlying strata as derived from the drill records.

The results indicate that iron ores of the character under investigation do not produce an effect on the earth's magnetism large enough to be detected by ordinary magnetic observations even when the greatest care is taken. In the brown iron ore district the results at the different stations do not differ more than is to be expected, taking into account the error of observation and the uncertainty of the correction for diurnal variation, and there appears to be no relation between the small observed differences and the underlying ore bodies revealed by the drilling. The results at Red Mountain Gap show greater differences, but there is no apparent relation between them and the thickness of the ore body.

The vessels of the Coast and Geodetic Survey, operating in southeastern Alaska, continued during 1922 the investigation of areas of

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marked local disturbances in that region with a view to the determination of more details as to their extent and magnitude both on land and over water areas; these data will be valuable for the study of the relation of the observed disturbances to geologic formation as soon as information on the latter subject is available.

During the season of 1922 a number of gravity stations were established by the Coast and Geodetic Survey in Kansas, Oklahoma, and Texas at the request of the Director of the U. S. Geological Survey in order to throw some light on subsurface densities of the earth's material. A computation and adjustment of the gravity stations and a reduction of the stations for topography and compensation were completed during the month of March 1923, and the resulting gravity anomalies were furnished to the Director of the Geological Survey, where they will be studied by Dr. David White.

No additional information has become available since last year regarding the possible relation between gravity anomalies and local magnetic disturbances, and, until new instruments or new methods are available which will make it possible to secure gravity determinations more rapidly and in less accessible places than is possible with the pendulum, much progress is not to be expected. The Geophysical Laboratory, in co-operation with the Coast and Geodetic Survey, has been at work on the problem of devising such an instrument, but it is still in the experimental stage.

U. S. Coast and Geodetic Survey,
Washington, D. C.

REPORT OF ROME MEETING OF THE SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION, MAY 1922[1]

LOUIS A. BAUER, *Delegate*

A well-attended meeting of the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union was held at Rome, May 4 to 9, 1922. Representatives from Australia, Belgium, Brazil, France, Great Britain, Italy, Japan, Poland, Spain, Sweden, and the United States were present at various sessions. Besides discussion of the Agenda, which contained leading questions pertaining to terrestrial magnetism and electricity, reports were presented by national and other committees and by leading investigators.

Professor Tanakadate (Japan) tendered his resignation as president

[1] Presented at the meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

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of the Section, because of his inability to attend to the duties involved. Dr. Charles Chree (Great Britain) was then chosen president and Professor Luigi Palazzo (Italy) vice-president. According to the statutes, the secretary and director of the Central Bureau, Dr. Louis A. Bauer, continues in office until the next meeting, which will be held at Madrid, Spain, in 1924. Directors J. Jaumotte (Belgium) and Ch. Maurain (France), and Professor A. Tanakadate (Japan) were elected additional members of the Executive Committee. It was agreed that administrative matters should be left to the officers of the Section, who constitute the Bureau.

Five committees were appointed: (1) Committee on Magnetic Surveys and International Comparisons of Instruments (Louis A. Bauer, chairman); (2) Committee on Observational Work in Atmospheric Electricity to report on Objects, Instruments and Methods (G. C. Simpson, chairman); (3) Committee on Measures of Magnetic Characterization of Days; (4) Committee on Best Methods, Instruments, and Compilations of Polar Light Observations; (5) Committee to Consider and Report on Best Methods and Instruments for Earth-Current Observations (Sir Arthur Schuster, chairman). The appointment of chairmen of Committees 3 and 4 was deferred pending the early entrance into the Union of additional countries.

The representatives of the American Geophysical Union on these international committees are: Louis A. Bauer and N. H. Heck (No. 1); W. F. G. Swann (No. 2); R. L. Faris (No. 3); J. A. Fleming (No. 4); and S. J. Mauchly (secretary of No. 5).

The results of the meeting were embodied in the form of 20 Resolutions, which are published in the secretary's general report.[2]

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THE BERMUDA ANOMALY[1]

H. W. Fisk

The peculiar interest in the local magnetic disturbance in Bermuda arises from the geological conditions with which it is connected. The island is a submerged mountain of volcanic origin

[2] *Terr. Mag.*, vol. 27, 1922, pp. 89–100. For the complete transactions see Bulletin No. 3 of the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union (Johns Hopkins press, Baltimore, Maryland, October, 1923).

[1] Abstract of paper presented before Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

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covered with a coral limestone cap which, at the only point where a boring has been made, extends 250 feet below sea-level.

The Department of Terrestrial Magnetism made a magnetic survey of the island in 1907 and repeated a part of the work in the summer of 1922, carrying out at the same time some special investigations relating to local disturbances. In this later work extensive tests were made which failed to discover any magnetic properties in the limestone either in fragments or in large masses. The magnetic distribution, however, indicates that, besides the general disturbance affecting widely separated areas, there are others of local character that have their origin much nearer the surface. The compass-variometer, an instrument designed and constructed by the Department for the detection of small differences of horizontal intensity, was used to study a few limited areas in detail. In one such there were found differences of as much as 700 gammas (0.00700 C.G.S.) within less than 200 feet horizontal distance. There was no evidence of an artificial source for this disturbance. The soil at various points on the island was examined and found to be magnetic, though the distribution of these local disturbances could not be directly related to the depth or to other apparent properties of the soil. There are, therefore, a major or primary source of disturbance lying deep in the lower structure of the submerged mountain, and other minor or secondary sources lying in or near the surface, probably in the soil.

Diurnal-variation observations with field instruments were made in declination simultaneously by two observers stationed at two points between which the difference was near a maximum. The simultaneous differences remained practically constant, and no evidence of any change in the diurnal variation either in range or phase due to the existence of the disturbance was found. A similar series of observations was made for the inclination using earth inductors, obtaining a value every 15 or 20 minutes, and for horizontal intensity using the method of deflections at one distance repeated at similar intervals. For these elements good diurnal-variation curves were obtained, although, because of the magnitude of unavoidable errors of observation, they were not a satisfactory basis for any conclusions.

In the course of the work in 1907, five stations were chosen as repeat stations and carefully marked for reoccupation. Two of these were reoccupied in 1910 by the *Carnegie* party, and all were reoccupied in 1922. The small differences in the 15-year change in inclination and horizontal intensity at the different stations show a slight tendency to vary with the value of the element. When the

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results from the nearest magnetic observatories are available, by which an approximate reduction of observations at all stations to a common epoch may be made, it may be possible to determine whether this tendency is real. In the case of the declination, the evidence is positive. The two stations which were occupied in August 1907, in January 1910, and in August 1922 were found to have declinations which differed by 3° 53′, 3° 59′, and 4° 18′ on the three occasions respectively, showing a steady increase in the difference with time. This increase seems to be related in some way to the declination at the two stations and is suggested also by the results at the other stations; for if the 15-year change is plotted for each of the five stations, using the declination as abscissae, the points fall near a line within limits on the order of the uncertainties of determination. It is hoped that a further refinement of the intensity observations may make it possible to reveal a connection between this phenomenon and the components of the disturbance field.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THE EARTH-INDUCTOR COMPASS[1]

P. R. Heyl

The earth-inductor compass for airplanes, as developed at the Bureau of Standards contains several novel features:

1. A null method is used for the indications. As long as the ship holds the prescribed course, the needle of the indicating galvanometer reads zero. A deviation from the course on either side is accompanied by a corresponding movement of the needle, which thus acts as a turn-indicator.

2. An iron core is used in the indicator, enabling the instrument to be designed of a small size.

3. Rolling and pitching errors are eliminated by a specially damped gimbal suspension.

4. A means is provided of distinguishing between north and south, or, in general, between any two opposite bearings.

5. A distant electrical control is used, by means of which the inductor can be located at a distance from the engine, and the course-setting device and indicator be located at the instrument board.

Bureau of Standards,
Washington, D. C.

[1] Abstract of paper presented before Section (d) of the American Geophysical Union, April 18, 1923.

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MAGNETIC METHODS FOR LOCATING IRON ORE[1]

N. H. Heck

At the request of Dr. W. E. Crane, Superintendent, Southern Experiment Station, Bureau of Mines, Birmingham, Alabama, observations were made by the Coast and Geodetic Survey to determine whether or not so-called non-magnetic iron ore affected the magnetic needle sufficiently to use this method in the investigation of iron ore deposits. The possibility was rather doubtful, but the commercial importance of such a method warranted the investigation.

The total intensity was obtained from plain dip, and dip with loaded needle, the dip needle not being reversed in polarity during the season, and the loaded needle lying nearly horizontal. The reduction factor and temperature coefficient of loaded needle were determined at Cheltenham and verified at Birmingham. The total intensity was obtained from the expression $F=P \cos I' \csc (I-I')$, where F=total intensity, I' is dip with loaded needle, I is dip, and P is constant.

P reduced to 30° C. shows very slight change. It was found that an increase of 1° C. lowers loaded end of needle 3.09 minutes of arc. The regions of red ore (hematite) and brown ore (limonite) were each examined; observations were also made over large specimens of each ore in an undisturbed region.

Probable error of dip was 1 minute; loaded dip, 2 minutes; total intensity, 30γ. Diurnal variation was taken from Cheltenham, one magnetic storm occurring during observations.

Results: In brown ore region, variations in observations 10 feet apart were as great as for 100 feet; mean difference between adjoining poles was 3′.9 with maximum difference of 9′.7 in the loaded dip. The total range over the entire area was 18′. Less range was found in the other cases.

Conclusions: The observed differences are too near those of the probable error of observation to be significant. The needle is slightly affected by the presence of ore, but not sufficiently for interpretation.

Areas of Marked Local Disturbance

The recently discovered large areas of local disturbances in southeastern Alaska are described. The Port Snettisham area is described in the Journal of Terrestrial Magnetism for December 1922. An area of 70 square miles in Lynn Canal has been found to have local disturbances with a range of declination of 25°. A new area was

[1] Abstract of paper presented before Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

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found in Union Bay, Ernest Sound, with variation of 38° from the normal value for the region. Seven square miles of this area were investigated.

In other cases the investigation covered both land and water areas, the land observations being along the shores. At Port Snettisham and Union Bay two points of actual disturbances were indicated by observations. For the water areas the north end of the needle is drawn towards the shore where the maximum disturbance is noted, except in one case in Chilkat Inlet, where the needle apparently pointed away from the disturbed region and is deflected towards the area where normal values were observed—this is probably a local effect.

Attention was called to the large deflections in depths of water of from 400 to 800 feet. Need for geological investigation in this region was indicated.

U. S. Coast and Geodetic Survey,
Washington, D. C.

OBSERVATORY EQUIPMENT FOR RECORDING PHOTOGRAPHICALLY THE CONDUCTIVITY OF THE AIR[1]

S. J. Mauchly

The atmospheric-electric program at the observatories of the Department of Terrestrial Magnetism at Watheroo, Western Australia, and Huancayo, Peru, provides for separate continuous records of each of the unipolar conductivities, λ_+ and λ_-. The conductivity recording equipment for a given observatory consists of two subsidiary units, each of which is a modification of the well-known Gerdien conductivity apparatus similar, in general, to that described by Swann,[2] in 1917, but including certain features and improvements which have resulted from several years' experience, at Washington, with the original apparatus.

The records are obtained photographically by means of a quadrant electrometer and suitable accessories. One pair of quadrants of the electrometer is connected to the insulated central cylinder of the main condenser and the other to the case of the electrometer, which is maintained at a potential of the order of 100 volts. The two pairs of quadrants are permanently connected through a high-

[1] Abstract of paper read at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

[2] See "Apparatus for Automatically Recording the Electric Conductivity of the Air," by W. F. G. Swann, in "Annual Report of the Director of the Department of Terrestrial Magnetism" for the year 1917, *Year Book of the Carnegie Institution of Washington*, 1917, p. 279.

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resistance radioactive cell, of the type developed in the Department of Terrestrial Magnetism by Swann and the author,[8] and the apparatus is thus readily adjusted for a linear relation between electrometer deflection and conductivity. The arrangements for calibration and for the elimination of spurious effects due to leak and to radioactive materials in the atmosphere are similar in principle to those described by Swann (l.c.).

In each of the two subsidiary units the "outer cylinder" of the portable Gerdien apparatus is represented by the middle section of a vertical air-flow tube extending through both the roof and the floor of a specially designed instrument house. The air flow in each tube is maintained by a fan driven by a small electric motor, both the motors and the electric recording lamps being operated from a 32-volt storage battery. Air is taken in through a suitable hood above the roof and discharged into an open space about 40 cm. high between the raised floor and the level of the ground. There is thus little chance of air being drawn a second time through the apparatus, and the maintenance of satisfactory insulation is greatly facilitated by the fact that dust and moisture from the air stream are prevented from depositing on the insulators of the electrometers and accessory apparatus.

As a result of changes in the fan and the lower part of the tube, the rate of air flow has been increased sufficiently to insure against saturation current between the inner and outer cylinders even under the most severe recording conditions.

Characteristic performance data were given, and normal conductivity records obtained at the Watheroo Magnetic Observatory were shown.

Fuller description will appear in the *Journal of Terrestrial Magnetism and Atmospheric Electricity.*

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

PROGRESS OF THE MAGNETIC SURVEY OF THE UNITED STATES[1]

D. L. HAZARD

The first general magnetic survey of the United States, begun by the Coast and Geodetic Survey in 1900, was practically completed in 1915. It involved the determination of the three magnetic

[8] *Terr. Mag.*, vol. 22, 1917, pp. 1-21.

[1] Abstract of paper presented at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

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elements, declination, dip, and horizontal intensity, at nearly every county seat in the country, and the reoccupation from time to time of a sufficient number of repeat stations in all parts of the country, to determine the change of the magnetic elements with lapse of time and to make it possible to reduce the observed values to any desired common epoch. The collected results of this survey reduced to January 1, 1915, were published in United States Magnetic Tables and Magnetic Charts for 1915, together with magnetic charts showing graphically the distribution of the declination, dip, horizontal intensity, vertical intensity, and total intensity for that date.

This general survey showed that there are many regions in the United States where more detailed observations are required to develop the irregular distribution of the earth's magnetism, the so-called "areas of local disturbance." Since 1915 the field work has been largely devoted to the continued occupation of repeat stations and the establishment of more stations in disturbed areas. During and immediately after the war the force of observers was so small that little field work could be done other than to keep the secular-change data up to date, but in 1922 it was possible to resume the filling-in process.

While there has been an increasing number of requests for information regarding the earth's magnetism, particularly as to the change of declination with lapse of time in connection with the reestablishment of lost boundaries, it is clear that the use of the magnetic stations of the Coast and Geodetic Survey and the data available in the office of the Bureau is still far short of what it should be. Accordingly in 1922 the names of all county surveyors, so far as possible, were obtained from the State authorities and a circular letter was sent to each one having two objects in view: First, to call attention to the data in this office at his disposal, and second, to find out the present condition of the magnetic stations in his vicinity. This has resulted in a large increase in the number of requests for information and has brought out the fact that a large percentage of the magnetic stations have disappeared or are no longer suitable for use. Up to the end of March, 1923, reports had been received from 441 stations (about one-tenth of the whole number) of which 254 are no longer available. The establishment of new stations to meet local demands will be one of the most important practical features of the work in the immediate future.

Work of this character had already been undertaken early in 1922 in response to the request from the Florida Engineering Society for the establishment of a meridian line and magnetic station at every county seat.

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The work of 1922 also included an investigation in Alabama of the possibility of using magnetic instruments for the location of deposits of non-magnetic iron ore.

The investigation of areas of local disturbance in southeastern Alaska was continued over both land and water areas, the observations being limited to declination.

The magnetic observatories at Vieques, P. R., Cheltenham, Md., Tucson, Ariz., Sitka, Alaska, and Honolulu, Hawaii, have continued in operation. Receiving sets have been in use at Cheltenham and Honolulu for some time for obtaining wireless time-signals, and one is about to be installed at the Porto Rico Observatory on Vieques Island. This Observatory soon may have to be discontinued or removed, due to poor living conditions at Vieques.

At the Cheltenham Observatory preparations are under way for an investigation of the effect produced on magnetic variometers by earthquake waves, a test of Professor Reid's theory, and an investigation of the control of the temperature coefficient of variometers, based on Mr. Hartnell's discussion of theory of such variometers.

At the Rome meeting of the International Section of Terrestrial Magnetism and Electricity a resolution was adopted "that it is desirable there should be in every country at least one observatory making systematic atmospheric-electric observations * * *." The Coast and Geodetic Survey is in sympathy with this resolution and is prepared to undertake such observations as soon as the necessary instruments can be secured, at either the Cheltenham or the Tucson Observatory. It also desires to add the study of earth currents to the program of one of its observatories when funds are available for the purpose.

In the reduction and publication of the observatory results several new methods have been adopted to facilitate the work and reduce the cost. These methods were discussed in detail.

Among the important publications may be mentioned "Compass Surveys" and "Magnetic Declination in the United States for January 1, 1920," issued primarily for the use of local surveyors.

The paper on "Horizontal-Intensity Variometers" by George Hartnell, Magnetic Observer, published in 1922, gives in detail the mathematical theory of the instrument and will be of great assistance in its operation and adjustment.

The routine computations and publication of field and observatory results have been carried on systematically, the latest publications

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of observatory results being for 1919 and 1920 and of field results for 1921.

U. S. Coast and Geodetic Survey,
Washington, D. C.

SUMMARY OF RESULTS OF A RECENT ANALYSIS OF THE EARTH'S MAGNETIC FIELD FOR 1922[1]

LOUIS A. BAUER

A new analysis of the Earth's magnetic field was made for 1922 by the writer, with the assistance of various members of the Department of Terrestrial Magnetism, as free as possible from assumptions as to the systems composing the entire magnetic field, and restricted, for the present, to the region of the Earth (86 per cent), from 60° North to 60° South. A spherical harmonic series to the sixth degree, and in some cases to the seventh, was established separately for each of the rectangular components, X (positive towards North), Y (positive towards East), and Z (positive towards nadir); the Earth was treated as a spheroid of revolution. Only some of the chief conclusions can be given here; for details, reference must be made to the full publication:[2]

It is found that for a satisfactory representation of the observed data, it is necessary to recognize the existence of an internal magnetic system, I, an external system, E, and a non-potential system, N, or of three equivalent systems, X, Y, Z. The I-system constitutes about 94 per cent of the total magnetic field, and E and N, each about 3 per cent.

The secular variation of the Earth's magnetism is caused both by changes, with lapse of time, in the direction of magnetization and by changes in the intensity of magnetization; the latter quantity has been steadily diminishing during the past 80 years at the annual average rate of about 1/1,500 part.

The north end of the magnetic axis of the I-system during the past 80 years has been moving slowly towards the west, and apparently at the same time slowly towards the equator. Were we to suppose that the magnetic axis made a complete revolution around the Earth's axis of rotation, the indications are that the period would not be a few hundred years, but many thousand years.

For the Earth's internal uniform magnetic field, the following data

[1] Abstract of paper presented at the meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

[2] See *Terr. Mag.* for March-June 1923, pp. 1–28, and for September 1923, pp. 61–81.

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apply for 1922: The magnetic moment, M, is 8.04×10^{28} C.G.S.; the components of M, respectively parallel and perpendicular to the Earth's axis of rotation, are $M_p = 7.88 \times 10^{25}$ C.G.S., and $M_e = 1.60 \times 10^{25}$ C.G.S.; $M_p = 4.93\ M_e$. Were the Earth's magnetism uniformly distributed through the Earth, as it probably is not, the average intensity of magnetism would be 0.074 C.G.S. The magnetic axis intersects the North Hemisphere in latitude 78° 32′ North and longitude 69° 08′ West of Greenwich.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

NOTES ON THE ORIGIN OF THE EARTH'S MAGNETIC AND ELECTRIC FIELDS

W. F. G. Swann

No abstract is given for this paper which was presented at the meeting of the Section of Terrestrial Magnetism and Electricity, April 18, 1923, as the gist of it is contained in the address by the author before the second general session of the Union, April 17, 1923 (see pp. 60–68).

University of Minnesota,
Minneapolis, Minnesota.

OUR PRESENT KNOWLEDGE CONCERNING THE ATMOSPHERIC DISTURBANCES OF RADIO-TELEGRAPHY[1]

L. W. Austin

Our present knowledge concerning the atmospheric disturbances of radio-telegraphy is very limited, but in the following I have attempted to make a brief résumé of the known facts and generally accepted hypotheses.

Atmospheric disturbances, popularly called static, form the chief obstacle to the progress of radio-telegraphy and telephony. They give rise to troublesome noises in the telephone receivers, which frequently make the reception of signals at great distances impossible, even in the case of the most powerful transmitting stations. They are generally most violent during the warmer months, and are especially severe in the tropics. They differ in strength from year to year, and their intensity usually increases rapidly with the wave-length to which the receiving apparatus is tuned.

[1] Sub-report of Committee on Atmospheric-Electric Phenomena and Measurements in the Troposphere and Stratosphere presented at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

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The disturbances have been classified by Eccles according to their sound in the telephones as clicks, hissing, rumbling, and crashing. The clicks and hissing are of comparatively little importance, the first being thought to be due to distant flashes of lightning, and the second to the discharge of dust, snow, or rain, striking the antenna.

The rumbling type (grinders), which is the most common type of disturbance, is generally believed to consist of strongly damped electrical wave trains or of untuned single pulses. That this type of disturbance has sometimes a certain amount of tuning is shown by the fact that the individual discharges are not always heard simultaneously at different wave-lengths, but it is believed that the discharges are so numerous that since they occur at different frequencies, they form a kind of disturbance spectrum and thus appear in the receiving apparatus at every wave-length to which the antenna may be tuned. While nothing is definitely known as to the exact nature of the source of the rumbling disturbances, it is believed that they are probably produced in the upper atmosphere by electrical readjustments. The resulting electrical waves expand in a more or less spherical manner until the lower portions of the wave front strike the earth when they spread out guided by the earth and move off with a wave front which soon becomes practically vertical, exactly like the electrical waves started from the transmitter of an airplane. The more powerful rumbling disturbances seem to come frequently from definite centers which often appear to lie above mountainous regions; for example, a large proportion of these disturbances which have been noted along the coast of Oregon and Washington appear to come from the direction of Mt. Rainier. Other well-marked centers have been observed in the mountains back of San Francisco and San Diego. The centers mentioned appear to be nearly constant in position and have been continuously active since their first discovery in 1920. It is believed that there is also a center of great energy somewhere in southern Mexico which frequently produces receiving difficulties throughout the eastern United States where disturbances from the Allegheny Mountains are also noticed. Among other reported sources of rumbling disturbances are large cities, perhaps on account of their ascending currents of heated air, thunder clouds, though here they are apparently unconnected with the visible lightning flashes, which produce clicks, and the advancing edges of rain areas. It may be said that, in general, the rumbling disturbances more commonly originate above the land as ships far out at sea are comparatively little troubled by them.

The intensities of disturbances of the rumbling type seem to be closely connected with the seasonal variations in the height of the

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sun's path. Some observations in Africa, reported by Dr. R. B. Goldschmidt and R. Braillard, tend to show that radio stations close to the equator have two well-marked maxima during the year at the time when the path of the sun passes through the zenith.

When the disturbances are directive and come from a direction different from that of the signal which is being received, it is often possible to eliminate a large part of the disturbances and thus improve the reception by making use of unidirectional receiving apparatus. Unfortunately it generally happens that there are secondary centers, such as local clouds or near-by mountains, which act upon the receiving station from several directions at the same time.

Some situations have been found, notably in California, where the disturbances come almost entirely from one point. In these places reception from the direction of the Pacific Ocean can be made nearly free from atmospheric troubles.

In addition to the rumbling disturbances, crashes are often heard in the telephones which seem to differ in origin and character from the rumbling type. The difference in sound of the two types is not easily distinguishable for untrained observers, since the rumbling is frequently preceded by a crashing noise. The true crashing disturbance, however, is not followed by rumbling. There is little evidence that the crashes are directive in character, while there are a number of observations which tend to show that they occur simultaneously at widely distant stations; for example, at San Francisco and Honolulu. It has been suggested that they may be connected with solar outbursts, although there is little direct proof to this effect. Sometimes they appear to occur in large number on days when earth-current disturbances are noted on telegraph and cable lines. It is also thought by radio operators that the crashes are entirely untuned in character, since the individual crashes are observed frequently simultaneously on widely different wave-lengths.

The Chief Problems of Atmospheric Disturbances

1. There is need of systematic daily observations on the intensity of the atmospheric disturbances at a large number of points in all parts of the earth. It is desirable, where possible, to have this intensity measured in terms of electric voltage on the antenna expressed in volts per meter height. Eventually recording apparatus should be devised for automatically taking these observations.

2. Measurements are also needed on the prevailing direction of the directive types of disturbances at widely scattered stations. As soon as possible, recording instruments should be used for this purpose. A direction recorder has, I believe, already been constructed in Eng-

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land. These observations will probably show daily and seasonal shifts of prevailing direction, and will eventually indicate certain points as disturbance centers.

3. When these disturbance centers are identified, a study should be made of the meteorological and electrical conditions prevailing, which will perhaps throw light on the conditions under which the disturbances are produced.

4. Observations should be made on the simultaneity of individual disturbances at widely distant points, identifying as far as possible the type of disturbance.

5. The question of the directivity of the crashing type should be settled.

When sufficient information regarding these points has been collected, comparisons can be made between the disturbances and other natural phenomena, solar activity, the earth's electrical and magnetic phenomena, and those of seismology and volcanology.

U. S. Naval Radio Research Laboratory,
Bureau of Standards,
Washington, D. C.

THE WORK OF THE INTERNATIONAL UNION OF SCIENTIFIC RADIO TELEGRAPHY[1]

J. H. DELLINGER

The International Union of Scientific Radio Telegraphy, begun in July 1919, is organized: (1) To promote the scientific study of radio communication. (2) To aid and organize researches requiring co-operation on an international scale and to encourage the discussion and publication of the results of such researches. (3) To facilitate agreement upon common methods of measurement and the standardization of measuring instruments. The work is actually carried on through National Sections, which have been formed in the United States, Belgium, England, France, Italy, and Norway. Steps are being taken to create such committees also in Australia, Holland, Japan, and Spain.

The meeting at Brussels in 1922 organized four international "commissions" as follows: (1) Methods of measurement and standards. (2) Radio wave transmission phenomena. (3) Atmospheric disturbances. (4) "Liaisons."

The American Section, under the auspices of the National Research Council, in Washington, is made up of an Executive Committee and

[1] Abstract of paper presented before the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

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six technical committees. These technical committees are: (1) Radio Wave Transmission Phenomena. (1a) Variations of Radio Wave Direction. (2) Atmospheric Disturbances. (3) Methods of Measurement and Standards. (4) Measurement of Radiation Causing Interference. (5) Electron Tubes. (6) "Liaison."

There is fruitful work for many years in the programs as outlined for the committees and it should have value not only for the better understanding and use of radio but also in the problems of geophysics, composition of the atmosphere, etc. Observations at sea are likely to be of particular value, as they have been fewest in the past, and because the radio phenomena are in general less complicated than on land.

It is believed that radio is unique among the few fields having special adaptability to a large-scale international research program. The phenomena that must be studied are world-wide in extent, and yet are in large measure subject to control of the experimenters. It is a field of work that has large possibilities for the future, and the surface only has been touched in the work done so far. Great progress can be made in the understanding of radio phenomena when widespread observations are taken, similar to the organized observational work on weather, earthquake, and terrestrial magnetic phenomena.

U. S. Naval Radio Research Laboratory,
Bureau of Standards,
Washington, D. C.

ON THE DIURNAL VARIATION OF THE POTENTIAL GRADIENT OF ATMOSPHERIC ELECTRICITY[1]

S. J. MAUCHLY

Two years ago the author read before this section a paper giving the results of an analysis based upon all the diurnal-variation observations for potential gradient, conforming to an adopted standard, which had then been made aboard the *Carnegie*.[2] It may be recalled that when the observations for the Atlantic, Pacific, and Indian Oceans, respectively, were tabulated in the usual manner, according to the local time of observation, the mean curves showed the diurnal variation over each of the oceans to consist *almost entirely* of a well-defined 24-hour wave although the times of occurrence of, say, the maximum phase of this wave differed greatly for the several oceans.

[1] Sub-report from the Committee on "Atmospheric-Electric Phenomena and Measurements in the Troposphere and Stratosphere," read at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923.

[2] *Bulletin of the National Research Council*, No. 17, 1922, pp. 73–77.

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It was also shown that mean curves, for the several oceans, obtained after first referring each series of observations to G.M.T. indicated a roughly simultaneous occurrence of maximum and of minimum, respectively, over all the accessible ocean areas. It was further shown that the mean diurnal-variation curves from many leading observatories, especially those corresponding to high latitudes and to winter months in the Northern Hemisphere, were in better agreement when plotted according to G.M.T. than according to local time.

Since the publication of the foregoing conclusions additional observations aboard the *Carnegie* have increased by 50 per cent the number of ocean observations of the diurnal variation of the potential gradient. The results obtained from a separate reduction of the new material have confirmed those obtained in 1921, both as regards the preponderance of a 24-hour wave progressing approximately according to universal time and also as to the times of occurrence of its characteristic phases.

Enough data are now available to justify grouping according to time of year in order to determine whether the diurnal variation undergoes any material changes during the course of the year. Four mean curves, each representing all the observations in a given three-month period, show only minor differences in the variation. The general constancy as regards the chief features of the diurnal variation is perhaps most readily indicated by the results of a Fourier analysis which was made of the data corresponding to the several curves. It should be noted that the observations were all referred to G.M.T. and, therefore, that the phase angles given in the table refer to 0^h, midnight, G.M.T. (The absolute values of the potential gradient given in the table are subject to an increase of the order of 20 per cent on account of a corresponding increase in the adopted reduction factor over the one originally used.)

TABLE 1.—*Fourier analysis of the diurnal variation of the potential gradient (P) from observations aboard the Carnegie 1915–1921.*

$P = P_m + c_1 \sin(\theta + \varphi_1) + c_2 \sin(2\theta + \varphi_2) + \cdots$, θ is counted from 0^h, midnight G.M.T. In the table c_1, c_2, etc., are expressed in percentages of P_m.

Months	P_m	φ_1	φ_2	φ_3	φ_4	c_1	c_2	c_3	c_4	c_2/c_1
	V/m	°	°	°	°	%	%	%	%	
Feb.–Apr.	114	197	273	208	352	19	4	1	1	0.24
May–July	94	163	209	119	223	10	7	2	1	0.72
Aug.–Oct.	97	168	218	250	337	16	4	1	2	0.24
Nov.–Jan.	105	204	225	243	14	14	2	4	1	0.15
Year	102	187	221	228	348	15	4	1	1	0.25

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While there is an apparent variation in ϕ_1 with time of year it should be borne in mind that the number of observations now available for each quarter is not sufficient to insure the reality of such differences as are shown in Table 1. Similarly, the large value of c_2 for the months *May, June, and July,* may be due, at least in part, to the fact that this quarter is represented by somewhat fewer observations than the others.

A special method was employed to determine, if possible, whether any part of the diurnal variation of the potential gradient over the oceans enters in as a local-time effect. For this purpose a separate study was made of the observations from 24 selected days (12 pairs), the places of observations represented by each pair differing in longitude by 180°. A mean curve, *according to local time,* of these "compensated" observations shows a distinct 6-hour wave, but no evidence of any other wave of appreciable amplitude. According to Fourier analysis the amplitude of the 6-hour wave is about 3 per cent. of the mean-of-day value, P_m, and the corresponding phase angle, at local midnight, is zero. These results, so far as they go, are in good accord with the 6-hour wave found by L. A. Bauer in his analysis of the potential-gradient data from the Ebro Observatory[8] although they must, of course, be accepted with reserve on account of the relatively small amount of observational material from which they are derived.

With the confirmation of the occurrence, in the diurnal-variation of the potential gradient over the oceans, of a 24-hour wave progressing approximately according to universal time, increasing interest attaches to the investigation of the possible occurrence of a similar phenomenon at land stations. For this purpose a comparison was made of the results of all available Fourier analyses of the diurnal variation of the potential gradient as published by various authors from time to time, together with the results of many new analyses, made in the Department of Terrestrial Magnetism and based on published data which had not, heretofore, been thus utilized. For the purpose in hand the main comparison of stations was based on the phase angles (φ_1) of the first harmonic (24-hour wave) at 0^h, midnight, G.M.T., rather than on the corresponding phase angle (φ_1) at local midnight. The comparisons were carried out for each of the solstitial and equinoctial quarters, respectively. Space prevents giving here more than a summary of the results for months corresponding approximately to the northern winter, shown in Table 2. The symbols used in this table are briefly as follows: φ_1, the phase angle of the first harmonic at local midnight; $\overline{\varphi}_1$, the corresponding phase angle at 0^h, midnight, G.M.T.; G_1, the G.M.T.

[8] *Terr. Mag.*, vol. 27, 1922, p. 28.

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TABLE 2.—*Diurnal variation of potential gradient for months of northern winter. Results of Fourier analysis*

Place	Months	Years	Lat.	Long.	φ_1	$\bar{\varphi}_1$	G_1 (G.M.T.)	φ_2	c_1	c_2	c_2/c_1
			°	°	°	°	h.	°	%	%	
Karasjok	Nov.–Jan.	1903–04	69.3N	25.6E	189	215	15.7	155	35	14	0.41
Edinburgh	Oct.–Mch.	1912	55.9N	3.2W	222	219	15.4	161	21	6	0.30
Potsdam	Dec.	1904–08	52.4N	13.1E	206	219	15.4	179	22	5	0.25
Kew	Nov.–Feb.	1898–12	51.5N	0.3W	209	209	16.1	181	12	11	0.90
Paris	Nov.–Feb.	1895–99	48.8N	2.3E	223	225	15.0	206	22	10	0.47
Munich	Nov.–Dec.	1905–10	48.1N	11.6E	241	253	13.1	187	26	15	0.56
Kremsmünster	Nov.–Mch.	1902–11	48.0N	14.1E	212	226	14.9	172	30	13	0.43
Davos	Nov.–Jan.	1909–10	46.8N	9.8E	217	227	14.9	189	35	16	0.44
Lyons	Dec.–Feb.	1885–90	45.8N	4.8E	220	225	15.0	183	13	10	0.76
Trieste	Dec.–Feb.	1904–05	45.6N	13.8 E	226	240	14.0	212	55	5	0.09
Ebro	Dec.	1910–20	40.8N	0.5E	224	224	15.1	193	22	9	0.40
Baltimore	Oct.–Feb.	1885–86	39.3N	76.6W	255	178	18.1	239	14	9	0.66
Washington	Jan.	1918–21	39.0N	77.1W	257	180	18.0	161	19	9	0.48
Algiers	Nov.–Feb.	1912–17	36.8N	3.1E	234	237	14.2	114	32	8	0.26
Batavia	Oct.–Mch.	1887–90	6.2S	106.8E	70	177	18.2	220	64	23	0.36
Rio de Janeiro	Sept.–Feb.	1910–11	22.9S	43.2W	286	243	13.8	171	32	23	0.72
Melbourne	Dec.	1858–62	37.8S	145.0E	63	208	16.1	210	25	24	0.96
Cape Evans	Nov.–Jan.	1911–12	77.6S	166.4E	66	232	14.5	243	21	4	0.22
Carnegie	.....	.....	.....	.....	.....	204	16.4	—	14	2	0.15

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corresponding to the maximum phase of the 24-hour wave; φ_2, the phase angle of the second harmonic at local midnight; and P_m, c_1, and c_2, respectively, the mean-of-day value, and amplitudes of the 24-hour and 12-hour waves, expressed in percentages of P_m.

From an inspection of Table 2 it appears that the G.M.T. corresponding to maximum phase of the 24-hour wave (G_1) shows no greater variations than might quite properly be attributed, in the main, to local causes. For both equinoctial quarters the agreement is nearly as good as during the months of northern winter. Only during the months which correspond to the northern summer is there a wide scattering as regards the G.M.T. values of G_1. However, even during this quarter, the majority of the stations show only small changes in G_1, from the values for the remainder of the year. Throughout the year there are relatively few exceptions to the general rule that only at stations for which c_2 is greater than c_1 is there marked departure from the value of G_1 as derived from the corresponding observations aboard the *Carnegie*.

There seems, thus, no reason to doubt that a 24-hour wave, progressing approximately according to universal rather than local time is in evidence at most land stations as well as over the oceans, and that its apparent absence at any given station is, in general, due to the fact that it is masked by local effects of greater magnitude.

Fuller publication and discussion of the results of this investigation will appear in the *Journal of Terrestrial Magnetism and Atmospheric Electricity* for September 1923.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

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SECTION OF OCEANOGRAPHY

REPORT OF THE COMMITTEE ON SEDIMENTATION AND MARINE DEPOSITS

T. WAYLAND VAUGHAN, *Chairman*

The members of this Committee are H. F. Moore, C. E. Van Orstrand, H. S. Washington, and T. Wayland Vaughan, Chairman. During the year two meetings were held, one at the residence of the Chairman on November 17, 1922, in conjunction with the members of the Committee on Sedimentation of the Division of Geology and Geography, N. R. C., resident in Washington, and one at Ann Arbor, Mich., on December 27, 1922, in conjunction with a general meeting of the Committee on Sedimentation above mentioned.

During the past year the following investigations on marine sediments have been conducted or begun in the United States.

Delta deposits at the mouth of the Mississippi River, by A. C. Trowbridge, for the U. S. Army Engineers. A report setting forth the results of his investigations has been prepared by Professor Trowbridge and it is hoped that it will be published. A considerable body of valuable information on the physical features of the sediments, on the effect of salt water on the flocculation of river-borne material, and on the influence of currents in distributing the material on the sea-bottom was acquired.

Deposits in Pago Pago Harbor, Samoa.—M. N. Bramlette has described a set of bottom samples from Pago Pago Harbor for the Department of Marine Biology of the Carnegie Institution of Washington. Mechanical analyses of the samples were made by the U. S. Bureau of Soils and chemical analyses were made by L. G. Fairchild of the Chemical Laboratory of the U. S. Geological Survey. A report on these samples, accompanied by maps and diagrams, is almost ready for the printer.

Coral reef sands from the Bahamas.—An elaborate study of sands from behind the reef off Cocoanut Point, Andros Island, Bahamas, has been completed by M. I. Goldman of the U. S. Geological Survey, and a report has been prepared for publication. This study was made according to the method of Doctor Goldman's report on samples from Murray Island, Australia, in Carnegie Institution of Washington Publication 213.

Deep-sea samples from off the Bahamas, the Caribbean Sea, and off the south coast of Central America.—The mechanical analyses of about 50 samples from the regions above indicated have been made by the U. S. Bureau of Soils and the amount of material in a colloidal

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state in each estimated from the amount of water-vapor absorbed. Chemical analyses of fractions of the same samples have been completed by L. G. Fairchild of the U. S. Geological Survey. T. W. Vaughan has examined and classified a number of the samples but has not been able to complete a report on them.

Muds from the shoal waters of the Bahamas and Florida.—Much additional work has been done on the calcium-carbonate muds of the shoal waters of the Bahamas and Florida, as follows: Mechanical composition by the U. S. Bureau of Soils; the bacterial flora and the bacterial precipitation of calcium carbonate by K. F. Kellerman and N. R. Smith of the U. S. Bureau of Plant Industry; and the physical features and contained remains of organisms by T. W. Vaughan. C. B. Lipman concludes from studies at Tortugas, Florida, that denitrifying bacteria do not precipitate calcium carbonate from pure ocean water; but the experiments of Messrs. Kellerman and Smith show that these organisms do precipitate calcium carbonate when a small amount of organic matter is added to the bottom mud, and chemical analyses by E. T. Erickson of the U. S. Geological Survey show that the bottom mud contains organic matter. The actual rôle of bacteria in precipitating calcium carbonate has not been determined, but the fact seems established that as bottom living organisms they are competent agents.

Beach pebbles along the New England coast.—C. K. Wentworth has published a paper on this subject as one of the Shorter Contributions to Geology of the U. S. Geological Survey.

Bottom deposits of the Gulf of Maine.—An investigation of the bottom deposits of the Gulf of Maine has been initiated through cooperation between the U. S. Bureau of Fisheries, the U. S. Geological Survey, and the U. S. Bureau of Soils. The mechanical analyses are being made at the Bureau of Soils, and the chemical analyses are being made in the Chemical Laboratory of the Geological Survey. A report will be prepared by W. S. Burbank, who will describe the samples and discuss the significance of the results.

Miscellaneous investigations.—Besides the studies above enumerated, a number of other investigations need to be noticed. R. C. Wells has continued his experiments on the cementation of calcium-carbonate sands; E. M. Kindle has published in the Journal of Geology a paper on mud cracks on the surface of calcium-carbonate muds in southern Florida, and R. W. Sayles has made qualitative experiments to determine the possibility of the occurrence of seasonal banding in marine deposits. The last subject has also been considered by A. C. Trowbridge and Max Littlefield in connection with their studies of the sediments at the mouth of the Mississippi River. The discussions

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at the joint meeting of the Committee on Marine Sediments and of the Committee on Sedimentation of the Division of Geology and Geography, N. R. C., will be mimeographed and distributed as a part of the report of the Committee on Sedimentation.

This Committee is gratified to report so much progress on the investigation of marine deposits during the past year.

U. S. Geological Survey,
Washington, D. C.

REPORT OF COMMITTEE ON CONFORMATION AND TOPOGRAPHY OF OCEANIC BASINS

G. W. LITTLEHALES

In connection with a contribution published among the communications to the First Pan-Pacific Scientific Conference, entitled "The Problem of Ascertaining the Configuration of the Basin of the Pacific Ocean," occasion has been taken to refer to the manuscript sheets of the bathymetrical chart of the world, prepared by the U. S. Hydrographic Office, setting forth the authentic deep-sea soundings, as evidence of the small extent to which the oceanic basins have been sounded and as showing the inadequacy of existing measurements to define the contours of configuration beyond the continental shoulder. While it must be remembered that not all the recorded soundings could be entered in some parts of this chart, yet, where none are laid down, none have ever been measured: and in regions where soundings are represented, if all the recorded soundings could be included instead of the selection which is given where the room does not allow more to be shown, there would yet be too few in general to serve for the delineation of contours of configuration of the bottom of the ocean. Nevertheless, there are some parts of the ocean where the number and distribution of the measurements have proved sufficient to afford an approach toward a fulfilment of this purpose, notably in the lane extending from California to Hawaii, of which a contoured map and profiles are published in United States Senate Executive Document No. 153, 52nd Congress, 1st Session, being the Report of the Results of the Survey for the Purpose of Determining the Practicability of Laying a Telegraphic Cable between the United States and the Hawaiian Islands. And, recently, the method of measuring the depth of the ocean by means of the Sonic-Depth Finder has been employed in the survey of a tract of the bottom of the Pacific Ocean 34,000 square miles in extent, bordering the coast from San Francisco to San Diego and extending seaward to the depth of 2,000 fathoms. A map of the topography of the ocean floor resulting from this sur-

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vey by two vessels of the Navy in the course of 34 days was presented with the report.

This map is of great significance to the Committee on Conformation and Topography of the Oceanic Basins because it seems to indicate that the mapping of the oceanic basins has been brought within the range of feasibility. Other important accessions, from American sources, to the accumulated data in relation to the configuration of the oceanic basins have resulted from the measurements by sonic depth finder at close intervals across the Atlantic from Narragansett Bay to Gibraltar and thence through the Mediterranean Sea to the Suez Canal, of which profiles were presented.

U. S. Hydrographic Office,
Washington, D. C.

A MATHEMATICAL THEORY OF THE TEMPERATURE DISTRIBUTION IN WATER DUE TO SOLAR RADIATION, EVAPORATION AND CONVECTION

GEORGE F. MCEWEN

The distribution of heat, chemical properties, and substances dissolved in the water of reservoirs, lakes and oceans depends both upon external agencies and the internal processes of conduction, and diffusion. But the latter phenomena taking place in large bodies of water, are entirely different in kind from what controlled laboratory experiments reveal. The well-known laws of conduction and diffusion deduced from *laboratory* experiments can not be carried over into the *field* where the corresponding phenomena are of a large scale type peculiar to nature.

This paper presents an attempt to formulate a set of assumptions, underlying phenomena of heat conduction, based upon field observations, and to deduce from them corresponding mathematical formulae involving the external agencies, solar radiation and evaporation as well as the internal convective or alternating circulation of the water. The convective process resulting in a mingling of small portions of the water is always present, and at the same time a general drift or current either vertical or horizontal may exist and can be taken into account in the theory, but is not considered here. A brief statement of assumption follows. The solar radiation penetrating the surface decreases in intensity according to a simple exponential law. The rate of evaporation is the same throughout the whole surface area, and the resultant increase in specific gravity of any small volume at the surface destroys its equilibrium, thus causing it to descend. It is assumed that the amount of increase in specific gravity

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required to cause the descent of any particle varies throughout the surface. Thus, the number of particles of a given specific gravity descending at any time decreases as the specific gravity increases, while the downward velocity of each is assumed to be proportional to the difference between its specific gravity and the general average value at that level. There is a continual disturbance of the equilibrium resulting in a succession of overturning motions each following a sufficient increase of stress in the system. Only those particles whose specific gravity exceeds the average value at any given level will descend below that level, and displace upward an equal amount of water per unit time.

Mathematical formulae corresponding to these assumptions have been derived. By means of these formulae, from observations of temperature and salinity alone, the rate of evaporation at the surface, the rate at which solar radiation penetrates the surface, and the absorbtion coefficient of radiation in water can be computed. Preliminary computations based upon both lake and ocean data have given values in good agreement with what would be expected from available direct observations of their values. However, it is necessary for a satisfactory test of the theory that all these related quantities be simultaneously *observed* in the same body of water. But, the approximate verification already obtained indicates that the basal idea already developed is applicable, although certain refinements of the theory will likely be found to increase the accuracy of computed results.

If the mechanism of the convective circulation thus deduced from principles of mechanics and heat conforms closely enough to actual conditions, the same theory also affords a means of dealing with phenomena of diffusion and even fluid friction. Such an extension of the application of the theory may be expected from the generally accepted idea that both diffusion and viscosity "so called" in large bodies of water are really due to convection or the interchange of water particles or small portions of water having different properties.

A paper presenting, in detail, the development of the theory and its application to a variety of field data is in preparation.

Scripps Institution of the University of California,
La Jolla, California.

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NOTE ON THE RELATIVE ACCURACY OF THE DETERMINATION OF MEAN SEA-LEVEL, AND EXTENSIVE LINES OF LAND LEVELING

W. Bell Dawson, M.A., D.Sc., M.Inst.C.E.

To obtain mean sea-level from tidal observations, a summation of the heights at each hour throughout the year is made; the heights being measured from any low-level plane of reference which is maintained at a constant elevation. The average value of this summation is the elevation of mean sea-level above the plane of reference. The variation between the determination in any one complete year and in a long series of years, will rarely exceed 0.10 foot, plus or minus.

The average value of mean sea-level, based on 3 or 4 consecutive years of observation, has thus a high degree of accuracy; provided that the observations are taken with the precautions explained in the paper. The variation from year to year, is undoubtedly actual, as can be shown; but its cause we need not discuss, as we are here dealing merely with the question of accuracy.

An error of 0.10 foot as above, corresponds with an error in land leveling, as determined by the usual formula, on an extent of some 300 or 400 miles. Hence there is an advantage, in equating errors in leveling, in checking when practicable to do so, with determinations of mean sea-level on the seacoast, within the limits of this distance.

Tidal and Current Survey,
Ottawa, Canada.

ESTUARY TIDES: A COMPARISON OF METHODS OF COMPUTATION

W. Bell Dawson, D.Sc., F.R.S.C., *Superintendent of the Tidal and Current Survey of Canada*

Estuary tides are of great importance; because many of the largest harbours of the world are in estuaries. Ocean transportation is thus carried as far inland as possible. The situation of estuary harbours seems to be determined by the point on the estuary where the tide attains its maximum range, before the height of the tide begins to be cut off by the river slope.

The most generally used method for the calculation of tide tables, is the harmonic analysis; by which tidal constants are determined, to serve as a basis for the prediction of tides in a future year. This method answers well so long as the tide curve is symmetrical, as it is on the open coast of the ocean. The tidal constants are then almost wholly of an astronomical character, in accordance with the positions of the sun and moon. But when the tide passes over some

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hundreds of miles of relatively shallow water, or up an estuary of any considerable extent, other elements become too large to be ignored. These elements are hydraulic in character rather than astronomical; since they are due to the balance between the momentum of the tidal streams and the retardation of bottom and lateral friction; as well as to the contrary flow of the river against the incoming tidal undulation. The tide curve itself is modified; becoming steeper during the rise of the tide and longer and flatter during the fall.

To meet these changed conditions, additional factors are introduced into the harmonic series, known as "Compound tides" and "Overtides." But with those usually employed, the resulting predictions are often unsatisfactory. From investigations by the Tidal Institute of Liverpool, it would appear necessary to introduce an indefinite number of additional terms for these Compound tides and Overtides; and in analysing for these, it could not be known in advance which of them would prove important and which of them negligible. The analysis itself thus becomes almost hopelessly tedious; and further, when these constants are found, there is no Predicting Machine which could handle so many of them as would result. (Discussion invited on this question.)

In supplying tidal data for large regions, especially where there are land-locked areas and estuaries, it is only for a few carefully selected reference stations that primary predictions are made from tidal constants determined by harmonic analysis. Computations for secondary tide tables and for the prediction of the turn of tidal streams, must in turn be based on differences of time and on ratios; which are not necessarily constant, but may vary in some lunar period. The question therefore arises whether estuary ports cannot better be dealt with on this principle. The methods that have been tried for Quebec, in the St. Lawrence estuary, will furnish a good example of the two ways of arriving at the result desired.

There were 19 years of tidal observation at Quebec which had been submitted to harmonic analysis; but the predictions obtained were not satisfactory. The whole record was therefore re-examined, as the ice conditions in some winters caused serious disturbance; and in the spring months of some years the high freshet levels were not likely to be well represented by the harmonic terms (Sa and Ssa) which are intended to give this variation. Accordingly, seven years were selected from this long series which appeared to be quite satisfactory. The average constants derived from these years were used to fill gaps in seven other years in which some winter months had to be cut out because of unreliable curves due to ice obstruction in the river; and these seven years were then submitted to re-analysis. Even with

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this revised basis comprising the fourteen best years, the predictions are not what they should be; as there is at times a discrepancy of as much as 30 minutes as compared with observation, and largely in one direction. The trouble may be due in part to the freshet, which rises suddenly in April with the melting snows, and falls off till the end of June or July. Its rise also differs greatly in amount in different years; and it is questionable whether the harmonic terms that are supposed to represent this rise, do so adequately.

The alternative method is to begin with a port in the open estuary below Quebec, where the tide curve is still symmetrical, and may be assumed to be represented accurately by the harmonic constants. From the predictions for this port, the time of the tide at Quebec is then computed by some system of variable tidal differences. This method has also the advantage of dealing in a simple and adequate way with the freshet, as the variation in the general average difference for successive months will cover the freshet effect in retarding the tidal undulation.

Father Point, the Pilot station in the St. Lawrence estuary, was taken as the primary tidal station. The predictions there, are now based on sixteen years of harmonic analysis. It is 180 miles below Quebec, where the estuary is 28 miles wide; and it is within seven miles of the 100-fathom line, and is thus oceanic in its tidal characteristics. The tide curve is still quite symmetrical at Father Point, as shown by the following figures for the duration of the rise and fall of the tide at localities along the estuary:

Quebec	Duration of rise,	5^h	02^m	Duration of fall,	7^h	23^m
Grosse Isle	" "	5^h	22^m	" "	7^h	03^m
Orignaux Point	" "	6^h	00^m	" "	6^h	25^m
Rivière du Loup	" "	6^h	09^m	" "	6^h	16^m
Father Point	" "	6^h	13^m	" "	6^h	12^m

The time which the tidal undulation takes to travel from Father Point to Quebec is approximately 4½ hours for High Water and 5½ hours for Low Water. The average time is subject to variation however, in the three leading lunar periods; which are (1) The Synodic month, from New moon to New moon; the variation from Spring tides to Neap tides recurring in the half month. Its length is 57 half lunar days or tide-intervals. (2) The Anomalistic month of the moon's distance, from Perigee to Perigee; length 53¼ tide intervals. (3) The Declinational month; its length between the moon's successive crossings of the equator in the same direction, being 52¾ tide-intervals.

In the simultaneous observations of the tide at Father Point and

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Quebec during five years, the tidal differences were numbered in accordance with these three periods to determine the corresponding variations in the difference of time. In each year, the months of January and February were omitted because of disturbance of normal conditions by ice; and the months of March, April and May were averaged separately to determine the effect of the freshet in the spring. As a rule, the greater depth of water during the freshet increases the rate of travel of the positive undulation at High Water, whereas at Low Water the restricted channel-ways and greater speed of the current due to the additional freshet volume, retard the negative undulation. These effects are manifest in the river above Quebec, as shown by simultaneous observations in the tidal section of the river.

For the computation of High Water at Quebec, the result proved simple. The general average value of the time-difference, after the freshet months, was 4 h. 23 m. and the variation in the value from Springs to Neaps during the Synodic month was only one minute, plus or minus, which is negligible. In the freshet months, the value was 13 m. less than the general average in April and 6 m. less in May. (As early as March, the conditions seemed still to be disturbed; as the averages differed in different years.) As the calculation value for High Water is thus a constant, the lower values in the spring months can readily be allowed for.

For Low Water the general average of the time-difference was 5 h. 37 m. and distinct variation in the value was evident in each lunar month as follows:

Synodic, from Spring to Neaps .....Variation 34^m
Anomalistic, with the Moon's distance .....Variation 18^m
Declinational .....Extreme Variation 19^m

The moon's declination causes a heavy alteration in the successive differences in accordance with its upper and lower transits; and to treat this as a correction would involve a series of plus and minus values alternately, which would be inconvenient. The variation with declination was therefore used as the primary series of differences, which thus become all of one sign; the extreme values in the series being 5 h. 41 m. and 5 h. 23 m. The variations in the Synodic and Anomalistic months are then applied to this series as plus and minus corrections; the correction having the plus sign for quarter or half a month consecutively and the minus sign likewise; which is more convenient than an alternation, and reduces the chances of accidental error in the computation.

In determining these variations, the numbering and tabulation of

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the observed time-differences in their respective periods, enabled the three variations to be reduced to the form of curves. From these, the primary values and the two series of corrections were read off in accordance with their respective numberings. In making the computation, the predicted times for Father Point during the coming year are numbered in three series in correspondence with the moon's position, which enables the values and corrections to be applied appropriately; the result affording the desired time of the tide at Quebec.

In investigating the freshet effect upon Low Water, little deviation from the general average was found in the spring months. This appears to result from the considerable depth which extends most of the way from Father Point to Quebec; so that the increase of depth during the freshet months compensated for the increased speed of the river flow against the tidal undulation. Above Quebec, where the depth is less, the time of Low Water is appreciably retarded during the freshet, as compared with other months.

It was therefore assumed in dealing with the Low Water values, that the form and amplitude of the various curves of variation would not be modified in the freshet months, even if the axis of the curve, which represents the general average, were altered in position. The freshet months were accordingly included, to extend the number of months on which the variations were based; making ten in each of the five years with one exception, or 49 months in all.

Correct tide tables for Quebec are unusually important, because the time of the tide at up-river points is derived in turn from them, as far as Lake St. Peter at the head of tide water, 105 miles above Quebec. The crucial point in St. Lawrence navigation is in this stretch, at a point named Cap à la Roche, where rock dredging is still in progress to bring the channel to standard depth. The tide at this point is computed from Quebec by means of two series of differences of time, for High Water and Low Water respectively, in successive months, as the level of the river falls from spring to autumn. In the case of Low Water, the variation during the course of the Synodic month is also allowed for. The computation for time is thus based entirely upon Quebec; the rise of the tide being determined on an independent system.

A test for the accuracy of the method herein described, was based upon the "average error" during the month, between the tide as observed and the time of the tide as predicted or calculated. This average error is the mean amount, irrespective of the plus or minus sign; which affords a consistent comparison.

The Low Water values were used for the test, as calculated for Quebec by the three series of variables, during three months in

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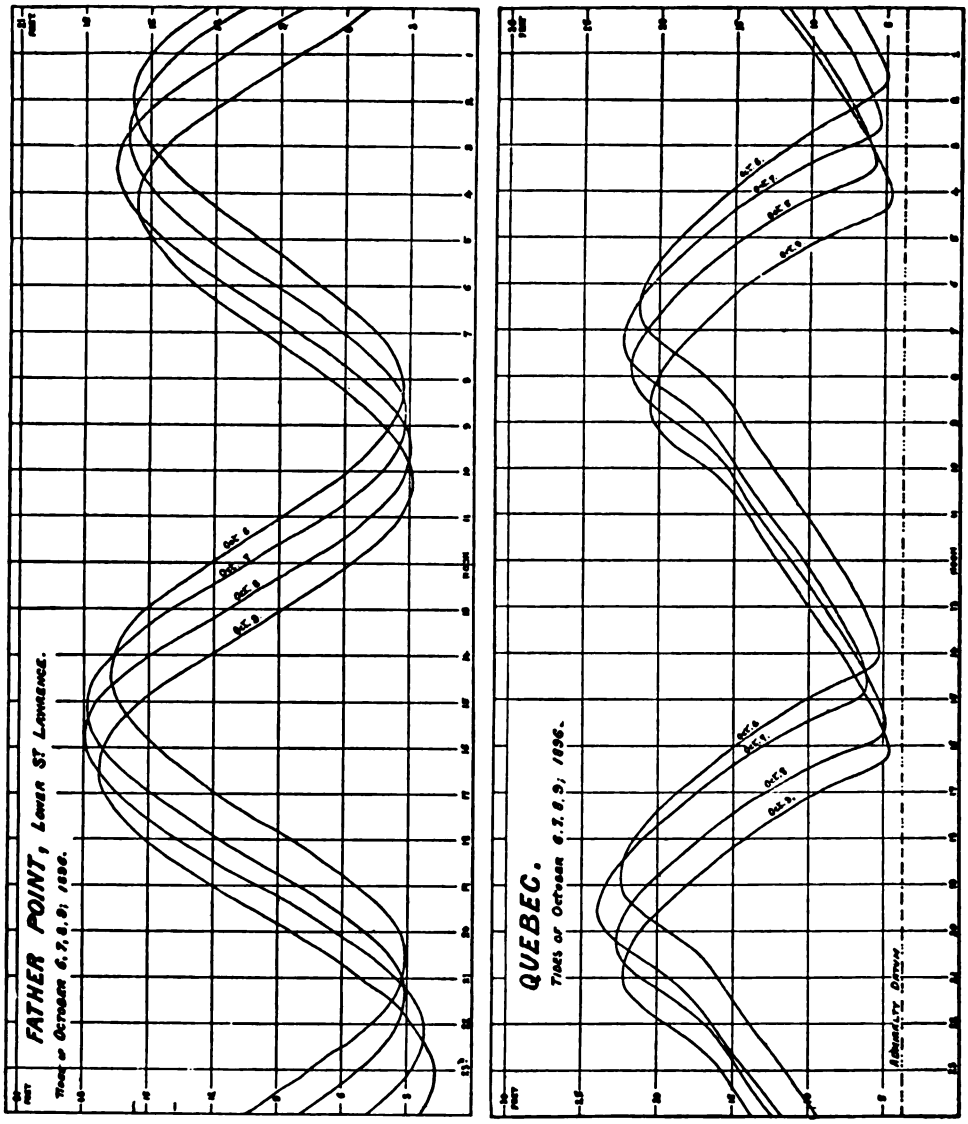

FIGURE 1.—Simultaneous tidal observations at Father Point and Quebec for the period Oct. 6–9, 1896, illustrating the smooth oceanic tidal curve at Father Point and the irregular river tide at Quebec.

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1922; the variables being applied to the predictions for Father Point as obtained from the harmonic constants. The improvement obtained, as compared with the harmonic predictions for Quebec, is as follows:

Predictions from Harmonic analysis. Average error in the month, 26 minutes.

Calculation by method explained. Average error in the month, 6 to 8 minutes.

As a further test, the time of Low Water at Quebec was calculated by this method from the time as actually observed at Father Point. The average error in the month was substantially the same as above, namely 6 to 7½ minutes.

The predictions for Father Point, based on fifteen years of harmonic analysis, when compared with the observed time of Low Water there, showed an average error during the month of 6 minutes. The values for Quebec, as given by this method, have thus practically as high an accuracy as the predictions for Father Point itself, on which the calculation for Quebec is based.

The High Water values at Quebec, when calculated by the constant time-difference from Father Point, also show an improvement as compared with the predictions obtained from the harmonic constants for Quebec. The average error during the month, between observed high water and predictions by the harmonic analysis, is 8 to 12 minutes; and by this new method based on Father Point, it is only 4 to 6 minutes. This is remarkably good, when the average error in high water as predicted by the harmonic constants for Father Point itself, is 6 minutes.

Tidal and Current Survey,
Ottawa, Canada.

SOME RECENT OCEAN HYDROGRAPHY BY THE U. S. COAST AND GEODETIC SURVEY

W. E. Parker

The purpose of this paper is to show that a considerable amount of oceanographic data can be obtained by public vessels at comparatively small cost without seriously interfering with their regular duties and that it is not necessary to defer further exploration of the oceans until such time as well-equipped expeditions can be organized.

During the spring and summer of 1919, and again during the summer and fall of 1922, the U. S. Coast and Geodetic Survey had oc-

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casion to transfer several of its surveying vessels from the Atlantic to the Pacific and vice versa.

Advantage was taken of these necessary passages from one coast of the United States to the other to explore the waters through which the vessels were required to pass. Each vessel was required to carry a line of soundings from the port of departure to the port of arrival on the other coast, and each was given a slightly different route so that there would be no duplication of work.

In this way an area of the Atlantic Ocean from Cape Hatteras to the Bahama Islands, 150 to 240 miles wide, of the Caribbean Sea along the steamer route from the Windward Passage to the Panama Canal 120 miles wide, and of the Pacific Ocean from Panama to San Diego, California, 100 to 150 miles wide, was surveyed in considerable detail.

A total of 587 deep sea soundings were taken by the most accurate method known. More than 1,000 temperature observations were taken at the surface, at a depth of 200 fathoms and at the bottom, and several hundred samples of sea water and of bottom material were preserved and forwarded to Washington for analysis.

Some of the most important geographical information obtained by those vessels was, the exact depths over the bank which lies south of Jamaica, proof of the non-existence of the bank supposed to lie about seventeen miles north of Panama, definite location of the Alijos Rocks, and the discovery of a bank midway between Guadaloupe Island and the mainland.

The cost of obtaining all of this data was truly insignificant. Since the vessels were required to make the passages in going to and from their stations, the only expenses which can properly be charged against this work are for special equipment purchased for the work, and for the overhead cost of the vessels, including pay of officials and men for the time required to make the passages in excess of the time which would have been necessary had no survey work been done.

The total time devoted to this work by all of the vessels, six in number, one vessel making the passage twice, was twenty-one days. The total cost of the work, including all expenses, was a little less than $9,000. About 1,000,000 square miles of ocean was explored.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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SECTIONS OF VOLCANOLOGY AND GEOPHYSICAL CHEMISTRY

SYMPOSIUM ON HOT SPRINGS[1]

ROBERT B. SOSMAN

A joint meeting of the Sections of Volcanology and Geophysical Chemistry of the American Geophysical Union was held at the Carnegie Institution of Washington on April 18, 1923, and was devoted to a symposium and discussion on the temperatures of hot springs and the sources of their heat and water supply. Ten papers were presented.

The temperatures of hot springs range all the way from those found in warm springs in the mountains of Virginia, some of which are only slightly above the annual mean temperature, up through boiling springs and mud pots such as are found in our western volcanic regions, to fumarole temperatures of about 650° C., the highest temperature found in the Valley of Ten Thousand Smokes, Alaska, reported on by E. G. Zies in his paper on "Hot Springs and Fumaroles of the Katmai Region."

E. T. Allen, in his paper on "The Hot Springs of Mt. Lassen," showed that chemical reactions, such as could be inferred from the composition of the spring waters, are not adequate to account for more than a very small proportion of the heat. Similarly, radioactivity, so far as it can be inferred from the radioactivity of "The Hot Springs of Iceland," described by F. E. Wright, is also insufficient to supply much heat. The radioactivity shows no parallelism with the temperatures of the springs, as has been shown by Thorkkelsson in Iceland, and by Schlundt and Moore in the Yellowstone.

L. H. Adams discussed "Physical Sources of Heat in Springs," showing that the forced flow of a fluid from a high to a low pressure through a porous plug may develop considerable heat—for liquids, as much as 40° C. for 1000 atmospheres fall. In fact, the passage of any material from a region of high pressure to one of low pressure will usually produce a rise in temperature. Such a process may be a source of heat in rock magmas. G. W. Morey, in his paper on "Relation of Crystallization to the Water Content and Vapor Pressure of Water in a Cooling Magma," showed that similar heat effects could be obtained by the forced flow of steam. These physical sources of heat have not been considered heretofore, and geological observations are lacking to indicate to what extent forced flow is a factor in natural processes.

There seemed to be general agreement, however, in the papers and

[1] Reprinted, with minor changes, from Journal of Industrial and Engineering Chemistry, vol. 15, No. 6, p. 610, June 1923.

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in the discussion, that the source of heat is in subcrustal rock magmas whether it escaped by the familiar processes of conduction and convection, or whether the process of flow played an important part. C. E. Van Orstrand, in his paper on "Temperatures in Some Springs and Geysers in Yellowstone National Park," estimated from temperatures in deep borings that most of the heat might be coming from depths between 3400 and 8000 ft.

Agreement was not so general as to the sources of the water supply. In the Yellowstone, as described by Van Orstrand, a considerable proportion of the water must be meteoric—that is, from rain and snow. The same is probably true in Iceland, where there is a large supply from snow fields and glaciers. Allen believes that the probability is strong that over half of the water in the springs of Mt. Lassen is from such sources, and A. L. Day showed that the water of "The Hot Springs of 'The Geysers' Region of California" is also mainly meteoric.

On the other hand, it was brought out in the discussion that the amount of water which may be dissolved in a batholithic magma of the chemical character described by Morey may be sufficient to supply small hot springs for hundreds of thousands of years without any addition of surface water, and Morey also showed that the conditions of crystallization of such a magma may yield water vapor under considerable pressure. It seems very reasonable to suppose that a considerable proportion of the water in such places as "The Hot Springs of Vulcano and Kalamaki," described by H. S. Washington, might be original magmatic water. This seems almost a necessary conclusion for some of "The Hot Springs of Southern Idaho," described by O. E. Meinzer. It was shown very clearly in the paper by Meinzer that there is no artesian source of water for many of the springs. It was also shown that on the whole the hotter springs are the smaller, indicating that dilution with ground water from moderate depths is responsible at the same time for low temperature and large volume. These springs come through Paleozoic rocks, Cretaceous granite, etc., and have no direct relation to the Snake River basalts, which are now quite cold.

A paper by Kirk Bryan on "The Hot Springs of Arkansas" was presented only by title as Mr. Bryan had to be absent on field work.

The publication in full of the papers and discussion is being considered. If they are so published it will be possible to add several other papers on other hot-spring areas of the United States, as well as communicated discussion, which will make this a valuable summary of the present status of our information on the subject.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

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Volume 6

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BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

July, 1925 **Number 53**

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SIXTH ANNUAL MEETING, APRIL 30 AND MAY 1, 1925
WASHINGTON, D. C.

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
OF
THE NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D. C.
1925

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BULLETIN

OF THE

NATIONAL RESEARCH COUNCIL

Vol. 10, Part 3 July, 1925 Number 53

TRANSACTIONS OF THE AMERICAN GEOPHYSICAL UNION SIXTH ANNUAL MEETING, APRIL 30-MAY 1. 1925,[1] WASHINGTON, D. C.

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[1] Of the Fifth Annual Meeting of the American Geophysical Union held May 3, 1924, no Bulletin of Transactions was published.

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GENERAL

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STATUTES AND BY-LAWS OF THE AMERICAN GEOPHYSICAL UNION

(As amended to May, 1925)

PREAMBLE

The American Geophysical Union is hereby established by the National Research Council. It supersedes the "American Section of the proposed International Geophysical Union." The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The American Geophysical Union is constituted as follows:

ARTICLE 1

Objects

(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and co-ordinate researches which depend upon international co-operation, and to provide for their scientific discussion and publication; and to facilitate special researches, such as the comparison of instruments used in different countries.

(b) To promote and co-ordinate the study of the various branches of geodesy and geophysics in the United States of America and its outlying territories.

ARTICLE 2

Membership

The membership of the American Geophysical Union shall be as follows:

(a) Those who composed the membership of the "American Section of the proposed International Geophysical Union" on July 1, 1919.

(b) Those who may be appointed by the Executive Board of the National Research Council upon nominations submitted by the Executive Committee of the American Geophysical Union.

(c) The Chairman of the Division of Foreign Relations, the Chairman of the Division of Physical Sciences, the Chairman of the Division of Chemistry and Chemical Technology, the Chairman of the Division of Geology and Geography, and the Chairman of the Division of Biology and Agriculture, of the National Research Council, members *ex officio*.

(d) The American officers of the International Geodetic and Geophysical Union and of its Sections, members *ex officio*.

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ARTICLE 3

Sections

The American Geophysical Union shall be divided into Sections, in accordance with the organization of the International Geodetic and Geophysical Union, as follows: (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Magnetism and Electricity; (e) Oceanography; and (f) Volcanology.

The members shall designate the Section, or Sections, to which they will belong. The *functions of the Sections*, in their respective fields, shall be the promotion of the objects of the American Geophysical Union.

ARTICLE 4

Officers of the American Geophysical Union

The *Officers of the American Geophysical Union* shall consist of a chairman and a vice-chairman, elected to serve for a period of three years, and not to be eligible for immediate re-election to their respective offices; and a general secretary, to serve for a period of three years.

ARTICLE 5

Officers of Sections

The *Officers of the Sections* of the American Geophysical Union shall consist for each Section of a chairman, a vice-chairman, and a secretary, whose periods of office shall correspond to those of the Union. The Chairman of each Section shall have the power to appoint, with the right to vote, a representative of the Section to such meetings of the Executive Committee of the Union as he may be unable to attend.

ARTICLE 6

Executive Committee

The *Executive Committee* shall consist of the chairman, the vice-chairman, and the general secretary of the American Geophysical Union, and of one representative from each of the sections of the Union, who shall be the chairman thereof or a member appointed by him; and, in addition, *ex officio*, the American officers of the International Geodetic and Geophysical Union, and of its Sections, the chairman of each of the Standing Committees of the American Geophysical Union, and the chairman of each of the following Divisions of the National Research Council: Foreign Relations, Physical Sciences, Chemistry and Chemical Technology, Geology and Geography, and Biology and Agriculture. This Committee shall have charge of all administrative matters of the American Geophysical Union, and shall be the representative of the Union in its relations with the National Research Council and with the International Geodetic and Geophysical Union. The Executive Committee, in consultation with the Sections, shall nominate to the Executive Board of the National Research Council delegates, or representatives, to the meetings of the International Geodetic and Geophysical Union and of its Sections, in accordance with the regulations fixed by the International Research Council for the voting power of the United States of America.

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ARTICLE 7

Annual Meetings

The American Geophysical Union and its Sections shall meet annually at such time and place as may be chosen by the Executive Committee of the Union. The officers of the Union and of the Sections shall be elected at this annual meeting.

ARTICLE 8

Special Meetings

Special Meetings of the American Geophysical Union, or of its Sections, may be called when necessary by the respective chairmen.

ARTICLE 9

By-Laws

The American Geophysical Union is authorized to enact such by-laws as may be necessary for the performance of its functions and duties.

ARTICLE 10

Amendments

Amendments to the Statutes of the American Geophysical Union shall be subject to the approval of the National Research Council.

BY-LAWS

The fiscal year of the American Geophysical Union shall conform to the fiscal year of the National Research Council.

Standing committees on Statutes and By-Laws, on Membership, on Meetings, and on Budget, shall be appointed for the ensuing fiscal year by the Chairmen-elect of the Union prior to the beginning of each year.

All committees of the American Geophysical Union shall terminate at the end of the fiscal year for which they may be appointed.

Meetings of the Union shall be called at least thirty days in advance, and those present at the meeting shall constitute a quorum.

Meetings of the Executive Committee shall be called by the Chairman, and those present shall constitute a quorum.

Final action shall not be taken by the Executive Committee on matters affecting any Section in the absence of the Chairman of such Section, or his representative.

No mail ballot shall be closed until at least thirty days after the date of issue.

After thirty days' notice has been given, amendments to the Statutes (all of which are subject to the approval of the National Research Council) may be voted on either by mail or at a regular meeting of the Union.

Amendments to the By-Laws may be proposed either by mail or at a regular meeting; when voted on by mail they require for adoption a majority vote of the members; when voted on at a regular meeting they require for adoption a three-fourths vote of the members present.

Any amendment to the Statutes or By-Laws proposed by at least five mem-

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bers shall be submitted for vote to the members of the Union by the Executive Committee.

A member of the American Geophysical Union may be dropped from the Union by a three-fourths vote of the members of the Executive Committee.

Statutes and By-Laws adopted by a Section shall not conflict with the provisions of the Statutes and By-Laws of the Union.

Matters pertaining to a Section or Sections, and not pertaining to the Union as a whole, shall be acted upon by the Section or Sections concerned.

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REPORT OF THE MEETING OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION AND ITS SECTIONS HELD AT MADRID, OCTOBER 1-10, 1924. PREPARED BY THE DELEGATES FROM THE UNITED STATES

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THE SECOND GENERAL ASSEMBLY OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION

HARRY FIELDING REID, *Chairman of the Delegation from the United States*

The second general assembly of the Union took place in Madrid, beginning October 1, 1924, in the building of the National Parliament. The king of Spain presided at the first meeting and the proceedings consisted of addresses of welcome. Then for a week the several sections met in different rooms and discussed matters of special interest to themselves. There are now thirty nations adhering to the Union, and nearly all were represented by delegates or by proxy. The United States had but four delegates, which made it impossible to keep in close touch with the discussions of the seven sections. At the final meeting on October 8 the several sections reported the results of their conferences to the general assembly.

The section of geodesy adopted the Hayford spheroid as the spheroid of reference for geodetic work, and it is hoped that it will be accepted by all nations. If all locations are referred to the same spheroid it will help greatly in connecting up the triangulations of the different countries. The principle of isostasy was discussed and accepted, and its application will improve the accuracy of the triangulations. The reduction of observations in accordance with this principle will probably be carried out in Washington. It was decided to make determinations of relative gravity between the base stations of the several countries so that the relative gravity at all stations may be properly compared. This is of great value for the determination of the figure of the earth and for studies of isostasy. A world-net of longitudes is to be determined by radio; by carrying this net completely around the world systematic errors can be largely eliminated, and longitudes more accurately fixed. By repetition at a future date, any east-west movements of the continents can be measured. North-south movements can be determined from the observations at the latitude variation stations, three of which continued their observations throughout the war; the section of geodesy will assist, by appropriations in the reduction of these observations. Dr. F. A. V. Meinesz, of Holland, described a method of determining gravity at sea, by swinging pendulums in a submarine, sunk some thirty meters below the sea surface. The results of some observations in the Indian Ocean were very accordant and indicate a very close approach to isostatic equilibrium in that region.

In the seismological section, the question of publishing annual lists of earthquakes was discussed, and it was decided, largely on account of lack

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of funds, not to undertake this for the present; but Professor Turner will continue to issue the International Summary, which contains the records and locations of the more important shocks. It was decided that the transmission curve, which gives the time of transmission of earthquake waves from the origin to distant points, requires more study before an official curve could be adopted. Reports were made on the transmission of disturbances due to explosions, which travel more slowly than is indicated by the general transmission curve, due undoubtedly to the fact that they travel through the superficial part of the earth's crust. Reports were made on seismological work in Spain, which is being developed with much vigor; and on the work of the Carnegie Institution in California. The fault map of California and the diagrams of Anderson's new seismograph aroused much interest; also the account of De Quervain's large instrument which has been mounted at Zurich, and is giving satisfactory records of small shocks in the Alps. These instruments present a strong contrast; the former weighs a fraction of a gram, the latter twenty-one tons. The Japanese delegates gave interesting accounts of the great earthquake of 1923 before both the section of seismology and the section of geodesy. The Central Bureau announced that it would begin the publication of seismological memoirs. The committee on the troublesome subject of microseisms was continued.

The most important question discussed in the meteorological section was the project of compiling weather charts of the northern hemisphere for the third quarter of 1923. This is an important matter and could best be carried out by an international weather bureau. Some doubts were expressed as to the propriety of "placing money at the disposal of an existing state service for carrying on work of an international character in conjunction with a commission." Many other interesting questions were discussed: sampling air at great heights; measurement of relative brightness of ground and cloud; determination of the variations of the hydrogen content of the air; spectral measurements of solar radiation intensity, at Izana, Canary Isles; daily observations of temperature and pressure in the free air; observations of air-borne parasites; stations in mountainous districts and in the South Pacific, etc. The section recommended to the General Assembly the appointment of a committee to consider a simplification of the Gregorian calendar, and the recommendation was accepted.

In the section of terrestrial magnetism and atmospheric electricity, reports were made of work accomplished in various countries. The section highly commended the work of the Carnegie Institution in the determination of the magnetic elements all over the world. It called attention to the importance of magnetic and electric observations in high latitudes, and recommended the west coast of Greenland, and Jan Mayen

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Island or Spitzbergen, as suitable locations for observations. Magnetic data from high latitudes in years near sunspot maxima are very desirable. Observations to reduce atmospheric potential gradients to volts per meter over level ground are much needed. It is also most important to investigate the magnetic properties of rocks from all over the earth, and from different geological ages. An instrument to measure the vertical intensity of the earth's magnetic field in absolute measure is much to be desired.

The American proposal to approve explorations of the oceans was adopted by the section of oceanography and by the general assembly. Biological oceanographers have been admitted to this section.

The committee on glaciers, which was appointed by the International Geological Congress, has lapsed since the beginning of the war. The section of hydrology of the Union wishes to take up the problems of the variations of glaciers, and the Union made a small appropriation to enable Professor Mercanton, of Switzerland, to consult with members of this section and devise some means of continuing the records.

None of the American delegates was able to attend the meetings of the sections of volcanology, oceanography, or hydrology. This emphasizes the importance of making provision for at least one American delegate to each section at future meetings of the Union.

The arrangements for the entertainment of the delegates and their families were most elaborate. The king and queen of Spain received them at the royal palace; and the mayor of Madrid held a reception at the mayoralty. The reception committee (Sen. D. L. Cubillo, Chairman, Sen. D. J. Galbis, Secretary) were indefatigable in their efforts. Excursions were made to the most interesting places in the neighborhood of Madrid, including the city of Toledo, all at the expense of the committee; a concert was given at the opera house, the bull ring and the museums were thrown open; and the meetings closed with a banquet at the Hotel Ritz. I do not think such lavish hospitality could have been tendered in any other city of the world. After the meetings, excursions were arranged to the cities of southern Spain and to the eastern coast; everywhere the hospitality was most generous.

The next general assembly of the Union will be held at Prague in 1927.

The Johns Hopkins University,
Baltimore, Maryland.

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REPORT ON THE MADRID MEETING OF THE SECTION OF GEODESY, INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION

WILLIAM BOWIE, *Delegate*

Early in 1924 it was realized by the Executive Committee of the Section that the agenda for the Madrid meeting would be a very heavy one. As is well known, the geodetic work that is considered by the Section consists of a number of branches; among them may be enumerated—astronomic longitudes, latitudes and azimuths; measurement of base lines; triangulation of various degrees of precision; traverse, precise leveling, gravimetric surveys, mean sea level, which furnishes starting points for leveling; variation of latitude; projections; figure of the earth; the theory of isostasy; and trigonometric leveling.

Each of the foregoing subjects should be considered at an international conference, for it is only by securing the active co-operation of geodesists in the various countries that the best results can be obtained.

Under the circumstances, the meeting of the Section of Geodesy was called for on September 26, 1924, although the formal opening of the meeting of the Union as a whole was called for October 1. Two days prior to the meeting of the Section, the Executive Committee held a number of sessions to make the final plans for the meeting of the Section and to consider some matters of a technical nature which had been referred to the Committee by the meeting of the Section held at Rome in 1922. The Executive Committee perfected the organization for the Madrid meeting and made preliminary lists of Committees with their provisional membership, which committees were to handle the various items included in the Agenda. When the Section met on the 26th the fifteen committees were appointed and immediately the work of the Section was undertaken. It is unnecessary to go into the details of the proceedings of the various sessions, for they will be given in the report which will be issued by the Secretary of the Section of Geodesy.

I feel it appropriate, however, to make some general remarks on the desirable character of subjects which should come before an international scientific assembly. As is well known, the geodesists of the world organized an international association many years ago and the Section of Geodesy of the International Geodetic and Geophysical Union is working along somewhat the same lines as the old association. It is felt that there should come before the International Union only those questions upon which international agreement, co-operation or expression of opinion is desired. These are surely the purposes for which the conferences are called. There is no place or time for purely scientific papers of a detailed nature. Such matters require a great deal of time for

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presentation and, owing to the fact that not all the delegates know any common language well enough to follow a detailed oral presentation, the results of scientific accomplishments or descriptions of methods should be given in abstracts only, in what may be called national reports. Such national reports, which have always been a feature of international geodetic conferences, cover the work accomplished in each of the adhering countries during the interval since the previous conference.

In addition to the national reports, reporters for each of the branches of geodetic science cover in a general way their field, showing its present status and recent accomplishments. The national reports and the statements of the special reporters are almost invariably printed, or multigraphed, and distributed to the members present at the meeting. The presentation of these national reports and statements by the special reporters is almost invariably in abstract.

There is no question but that countries profit by having representatives to scientific meetings of an international character but it should be realized that, at such a convention as that of the International Geodetic and Geophysical Union, one representative can keep in touch with the work of a single section only. Many hours each day are given to the sessions of a section and, in addition, the delegate may be on several committees, and is sure to be on at least one. This means that the delegate has no time to attend the meetings of sections other than the one to which he may be accredited. Unfortunately, at Madrid there were only four official delegates from the United States; this meant that three Sections had to be neglected. It is hoped that at future meetings of the Union there will be at least one official representative from the United States to each of the Sections and to some of the Sections there should be two or more delegates.

Among the outstanding accomplishments of the Madrid meeting were the adoption of the Hayford spheroid, for use in triangulation computations in those countries which have not yet adopted a spheroid, or for those countries which, having adopted a spheroid in the past, wish to change to one which is nearer the truth. This spheroid will also be used for all scientific investigations. Plans were made for the extension of a net of longitude stations around the world, in co-operation with astronomic observatories. The transmission of signals for the comparison of the time-pieces at contiguous stations will be by radio. This longitude work will provide national base stations for longitude and will provide a means for checking the stability of the positions of continents and islands with reference to each other. Provision was made for continuing studies in the variation of latitude and for computation, reduction and publication of the results of the observations for the variation of latitude

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made during and just after the war. Preliminary plans were made to strengthen the network of national gravity base stations.

The National Committee for Geophysics of Spain is to be commended in the highest terms for its efforts in making perfect the arrangements for the meeting of the Union and its Sections. Not a single item that could add to the convenience or the comfort of the delegates was overlooked. The entertainments and excursions provided for were most delightful and did not materially interfere in any way with the serious work of the conference, except for the one day when the delegates were taken on special train to that most interesting city, Toledo. This break in the meetings of the Union furnished a splendid means for the delegates to become acquainted with each other, in as much as the trip to Toledo occurred very shortly after the beginning of the conference. Personal contact is most valuable at such a gathering in order to facilitate the proceedings.

The conference was honored by the presence of His Majesty the King at the opening meeting of the Union, at which he presided. As far as was known to the delegates present, this is the only occasion at an international scientific conference where the ruler of the country took so active a part in the proceedings. We all felt that this was an unparalleled tribute to science and to scientific workers.

There were present at the meetings of the Section of Geodesy fifty-six delegates and twenty-three guests, representing twenty-six countries.

The members of the Section felt that the results accomplished made the Madrid meeting the most productive one that had ever been held, even including the meetings of the old International Geodetic Association.

U. S. Coast and Geodetic Survey,
Washington, D. C.

REPORT OF THE MADRID MEETINGS OF THE INTERNATIONAL SECTION OF METEOROLOGY, INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

HERBERT H. KIMBALL, *Delegate*

Delegates to the Madrid Meetings of the International Union of Geodesy and Geophysics in October, 1924, will cherish the memory of the deep blue skies, the crisp, invigorating October atmosphere, and, above all, the hearty and open-handed hospitality of Spain. While especial mention should be made of Senors Cubello and Galbis of the Madrid committee for their efforts in our behalf, it was, after all, the Spanish nation, headed by their majesties the King and the Queen, and assisted by their ministers, that really gave to the meetings their setting of artistic beauty. It was refreshing as well as a relaxation to pass from

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the tenseness of a scientific conference to a reception in the Royal Palace, a concert in the Royal Theater, a banquet *à la Madrid,* or an excursion to a suburban restaurant, an art museum, a scientific observatory, or, for some of the delegates at least, even a bull fight.

The memory of these various delights forms the artistic background for our mind's picture of the scientific conferences, which engaged our days in Madrid, and about which I am now to speak to you, confining myself to the meetings of the Meteorological Section.

The agenda for the meetings, which had been made up from items proposed by the national committees of the adhering countries, covered a wide range of subjects. Sir Napier Shaw, President of the Section, before he left London spent many busy days in classifying these items, and assigning them to their proper place on the program. Then, after reaching Madrid, he had other proposed items handed to him by the delegates, upsetting his program, and making difficult the adequate consideration of important items already proposed.

Since items presented too late to be circulated among the adhering countries can only have a place on the agenda by unanimous consent, I think it would be well to inform the Bureau of Section C of the International Union that your delegate to the next conference will be instructed to withhold his consent to the consideration of these belated items.

The final action on the different items considered is expressed in twenty-seven resolutions that were adopted by the Section. These have already been published in full in the Monthly Weather Review for November, 1924, Vol. 52, pp. 533–536, and will be published later in the Proceedings of the Section. A brief summary follows.

Four resolutions refer questions to other organizations for consideration. Twelve others make recommendations or express an opinion, but do not contemplate action by the section. The remaining eleven resolutions call for action on the part of the section or of some of the national committtees, as follows:

1. The preparation of a card index of names for the regular distribution of the proceedings and the distribution of notices of prospective meetings.

2. Details of a plan for obtaining samples of air from great heights. (Assigned to the National Committee of the United States.) Fifty pounds may be appropriated for the observations at the discretion of the executive committee of the Section.

3. The appointment of a commission with a grant of £400, to purchase self-recording pyrheliometers for use in Northern Canada, Spitzbergen, New Zealand or Samoa, Amazon valley of Brazil or Belgian Congo, and Argentine for South Orkneys, and also for the purchase of instruments

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of Mr. Richardson's design for measuring the relative brightness of ground and cloud surfaces from airplanes, in the four countries having airplanes at their disposal, namely, France, Great Britain, Italy, The United States.

4. An illustrative application of the principles employed in each country for forecasting the weather. September 25, 1923 (forecast for the 26th) was selected as the day on which the application of the principles was to be illustrated.

5. Continuation of efforts to obtain pilot and sounding balloon observations over the sea and special regions over the land. The sum of £750 was placed at the disposal of the Bureau of the Section for this work, provided that £500 of this amount may be applied towards the publication of a year's results of observations of the upper air.

6. The international days of the Commission for the study of the upper air should be included in the days selected for the observations of atmospheric dust.

7. The appointment of a commission to arrange and advise concerning further investigation of atmospheric dust, including the relation between dust and visibility and also the potential gradient of atmospheric electricity.

8. An invitation to those who are interested, to circulate a calendar for the year 1925 showing how they would desire meteorological observations to be dealt with.

9. Finally, the Section decides to make, as an example, and on a precisely limited subject, a test of the services which would be rendered by an International Meteorological Bureau, the organization of which is now being studied by a commission of the International Meteorological Committee.

The problem to be solved, chosen from those which clearly involve international collaboration, is the following: The compilation of an atlas, or of bi-daily charts, covering the greatest possible part of the Northern Hemisphere, for the third quarter of the year 1923. M. La Cour, President of the North Atlantic Chart Commission, will have charge of the execution of the work. He will work under the instruction of a commission including members of the Union belonging to the above commission of the International Committee. A sum of £500 will be allotted for the work.

This last resolution was adopted in the face of considerable opposition, as it was considered unwise by some to "place money at the disposal of an existing state service for carrying on work of an international character in conjunction with a commission."

U. S. Weather Bureau,
Washington, D. C.

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REPORT OF MADRID MEETING OF INTERNATIONAL SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY, OCTOBER, 1924

LOUIS A. BAUER, *Delegate*

Bulletin No. 4 of the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union, consisting of ten pages and devoted to a General Report of the Madrid Meeting of the Section, was issued last December, by the writer, who was re-elected Secretary and Director of the Central Bureau of the International Section for the period 1924-1930. As a copy of this Bulletin has already been sent to each member of the Amerieaan Section, it will not be necessary to go into further detail here.

It will be of interest, however, to report that arrangements are already under way towards putting into effect some of the twenty-two resolutions which were passed at the Madrid meeting. Thus, word has been received from Dr. D. la Cour, director of the Danish Meteorological Institute, that, in accordance with Resolution No. 8, a permanent observatory will be established this coming summer at Godhavn, just south of Disco, on the west coast of Greenland. There are also indications that, following Resolution No. 10, the Canadian Government before long will fully equip the Meanook Magnetic Observatory; at the present time only photographic records of the variations of the magnetic declination are being obtained at this observatory, nearest of any to the North Magnetic Pole.

Information has also been received with regard to the prosecution of the magnetic survey of the Baltic Area (Resolution No. 21) and the magnetic survey of Norway.

The Apia Observatory, following the hope expressed in Resolution No. 13, is maintaining its full activity in terrestrial magnetism, atmospheric electricity, seismology, meteorology, etc., under the joint auspices of the New Zealand Government, the British Admiralty and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

Preliminary information is being collected by Prof. A. Tanakadate, as reporter, on the best means of accurately observing time of commencements of abrupt-magnetic disturbances (See Resolution 2*d*.). The Department of Terrestrial Magnetism of the Carnegie Institution of Washington and the United States Coast and Geodetic Survey have co-operatively investigated some recent cases of abrupt-magnetic disturbances, as recorded at eight magnetic observatories of the two respective organizations. The range in magnetic latitude of these observatories is from 46°.3 S to 82° N, and the data indicate that, on the average, it would take an abrupt disturbance from two to three minutes to progress from

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the magnetic equator to the magnetic poles; the correlation factor is on the order of 0.9 for the abrupt disturbances in the intensity of the Earth's magnetic field.

Renewed interest, following the recommendation expressed in Resolution No. 16, is being shown in upper air investigations pertaining to terrestrial magnetism, atmospheric electricity, and radiotelegraphy.

Since the Madrid meeting, word has been received that the Geophysical Commission of Norway has decided to take the necessary steps for joining the entire International Geodetic and Geophysical Union; heretofore, Norway had merely been an adherent to the International Section of Geodesy. Information is likewise at hand that other countries will soon join the Union, so that most likely by the time of the next meeting, to be held at Prague in 1927, the chief countries the world over will be adherents.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THE MADRID MEETING OF THE SECTION OF OCEANOGRAPHY, INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION

N. H. Heck

Eight countries were represented and two, Canada and the United States, sent reports. Prof. Odon de Buen of Spain was elected president of the Section in place of the Prince of Monaco, deceased, Dr. Magrini continuing as Secretary.

Secretary's Report.—The Secretary's report brings out the fact that with the suppression of the sub-section of Oceanography of the International Union of Biology which was established at Brussels, the name of the Section was changed from Section of Physical Oceanography to Section of Oceanography, to include both fields.

The function of the Section in co-ordinating the work of various commissions, such as that for the Atlantic and that for the Pacific, is of great importance. These commissions consist of government officials of countries interested, the commissions serving to co-ordinate the work, but with the individual nations preserving full autonomy.

Activities of the Section include:

1. Establishing of central library and catalogue. Good progress is being made but more contributions are needed. They are filed by authors, by subjects and by regions.

2. Publishing of bibliographical bulletin. This is making good progress. Authors are requested to use a special form in reporting their publications to insure uniformity.

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3. List of oceanographers. The first list has been prepared and is being distributed for correction. Each subsequent list is expected to be more complete.

4. Publication of international vocabulary of oceanography. Co-operation of the International Hydrographic Bureau is being secured.

5. Publication of international manual for observations to be made at sea. A proposal made at Rome was modified so that this would be published in three volumes containing respectively: I. Hydrography, Morphology and Lithology. II. Meteorology and Physics. III. Chemistry and Biology. A difficulty was encountered in that this work must go hand in hand with the international vocabulary of oceanography in order to insure uniformity of expression.

6. Exchange of publications was considered and its importance emphasized.

Reports of Commissions.—Commission of the Atlantic. Reports primarily on the existing organization, explain the part carried on by different nations and lack of co-ordination of certain parts of the work. A recommendation was made that secretaries of four existing organizations (two in Europe, one in North America, and one in Africa) join with a fifth to be selected for Latin America, to co-operate with the General Secretary in co-ordinating the work.

Commission of the Pacific. Reported by letter from the President, Dr. Littlehales. Lack of American co-operation is hindering co-operation of nations bordering on the Pacific. Proposed American Naval Expedition may remedy this. Present task is to co-ordinate work of Pan Pacific Scientific Congress and various branches of the National Research Council. Acceptance of delegation on commission by representatives of all nations concerned is promising of effective organization. (In this connection Dr. Littlehales's absence from Madrid is to be especially deplored.)

Commission of the Mediterranean made a report of primarily European interest.

Commission on Tides made a report in which the importance of records on oceanic islands was emphasized, also need for standard method by all nations for recording tidal currents. Need for joint study of mean sea level by oceanographers and geodesists was emphasized. Questions of local interest were discussed. Need for tide observations on the high seas was brought out. Co-ordination of methods of study of ocean currents and observation of mean sea level was discussed.

Commission for Application of Acoustic Methods to Depth Determination. Little information available to commission at that time, but proposition was made for co-ordination of study and methods and their ap-

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plication. International Hydrographic Bureau and individual national services were asked to co-operate.

Publication of National Reports. Reports declared very interesting but too voluminous to publish with limited funds available. Recommended that system be followed similar to that of geodesy of having national reports on oceanography printed in standard manner by each nation. Section of National Unions asked to co-operate.

Commission for Organization of Great International Campaigns. This Commission recommended that the Council for the Exploration of the Sea work in close co-operation with the Union and its President was elected third vice-president of the Section. A committee was appointed to determine on an international organization for the exploration of the sea.

A special report was made on a recommendation for an international expedition. The fact that most nations are unable, by themselves, to carry on such expeditions was emphasized, and the important results to be expected were brought out. A type of vessel was suggested. This expedition would be under the jurisdiction of the International Council for the Exploration of the Sea, and this organization proposed to take up the matter of support from the various countries interested.

American Naval plan was described. These plans do not interfere (except that American co-operation in the general plan is likely to be reduced if the naval plan is put into effect).

U. S. Coast and Geodetic Survey,
Washington, D. C.

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RESOLUTIONS

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RESOLUTION ON THE DEATH OF DR. JOHN FILLMORE HAYFORD, ADOPTED AT THE ANNUAL MEETING OF THE AMERICAN GEOPHYSICAL UNION, MAY 1, 1925

(Resolution was submitted by Section of Geodesy.)

Whereas, We, the members of the American Geophysical Union, have learned with sincere regret of the death, on March 10, 1925, of our associate, Dr. John Fillmore Hayford, Director of the College of Engineering of Northwestern University, therefore be it

Resolved, That we express our deep sorrow in the loss of this member, whose active work in the American Geophysical Union began with its organization in 1919. He held the office of Chairman of the Section of Geodesy from July 1, 1922, to June 30, 1924, and, not being eligible for immediate re-election, that of Vice-Chairman from July 1, 1924, until the time of his death.

Dr. Hayford enjoyed world-wide renown in the realm of geophysical science. For a number of years he was in general charge of the geodetic field and office work of the U. S. Coast and Geodetic Survey, during which time he unified the triangulation systems of the entire country by basing them upon a single point and on one spheroid of reference. He derived, from triangulation and astronomical data in the United States, a new spheroid which was adopted in 1924 by the Section of Geodesy of the International Geodetic and Geophysical Union as being the most reliable in existence and the one recommended for use in all scientific problems involving the shape and size of the earth and in all mapping and charting purposes by those countries which have not already adopted a spheroid for such work.

Dr. Hayford, while in charge of the geodetic work of the U. S. Coast and Geodetic Survey, was instrumental in initiating the revision of field and office methods and practices in conducting geodetic work, leading to greater efficiency and economy. He made the first comprehensive quantitative investigation of the theory of isostasy and thereby proved its validity. In recognition of this he was awarded, early in 1924, the Victoria Medal by the Royal Geographical Society of London.

During the war, Dr. Hayford was a member of the Advisory Committee on Aeronautics and, at the time of his death, was a Research Fellow of the Carnegie Institution of Washington, carrying on investigations concerning the levels of water in the Great Lakes.

The long list of scientific reports and papers by Dr. Hayford forms his fitting and lasting memorial.

Resolved, That the members of the American Geophysical Union re-

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gret the death of Dr. Hayford as a personal loss as well as a loss to the science of this country and the world, and that they express to his family their deepest sympathy.

Resolved, At the annual meeting of the American Geophysical Union, held on May 1, 1925, that a copy of these Resolutions be sent to Dr. Hayford's family and that they be spread on the Minutes of the Union.

RESOLUTIONS ON THE DEATH OF DR. ROBERT SIMPSON WOODWARD, ADOPTED AT THE ANNUAL MEETING OF THE AMERICAN GEOPHYSICAL UNION, MAY 1, 1925

Whereas, We, the members of the American Geophysical Union, have learned with deep regret of the death of our associate, Robert Simpson Woodward, who, after a lingering illness of 18 months, peacefully passed away on June 29, 1924, in the seventy-fifth year of his age, therefore be it

Resolved, That we express our deep sorrow in this loss of one who took a prominent part in the formulation of the initial plans which led to the ultimate establishment of this Union. Dr. Woodward's contributions to the various branches of geophysics, notably geodesy, are too well known to require enumeration here. He held positions of responsibility, both in governmental and university affairs, and was President of the Carnegie Institution of Washington from December, 1904, to January 1, 1921, when he voluntarily relinquished this position. He was the recipient of many honors, both from universities and learned academies. We cherish the memory of our late fellow member, not alone for his scientific achievements, but also for his sturdy philosophy and ever-hopeful outlook.

Resolved further, That the Secretary of the Union be instructed to transmit a copy of this Resolution to Mrs. Woodward, and that it be spread on the Minutes of the Union.

RESOLUTION IN REGARD TO CERTAIN COUNTRIES

Resolved, That the American Geophysical Union request the National Research Council to instruct its representatives at the meeting of the International Research Council, to be held in July, 1925, to endeavor to secure favorable action on the recommendations passed by the Division of Foreign Relations on April 26, 1925, with respect to future adhesion of countries to the International Research Council and to its several Unions, and the power of Unions to make, from time to time, such changes in their own statutes as circumstances may require.

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RESOLUTION REGARDING PROPOSED U. S. OCEANOGRAPHIC EXPEDITION

Whereas, The Secretary of the Navy recently convened a conference to consider all matters pertaining to a proposed U. S. Naval Expedition for research in oceanography, and

Whereas, Such a cruise unquestionably will be fruitful of results of interest to oceanographers and of value ot mankind, and

Whereas, The American Geophysical Union has interest in all matters dealing with oceanography, and particularly with the securing of quantitative data thereon,

Resolved, That the American Geophysical Union endorses the plan for such an expedition and expresses the hope that the necessary funds may be forthcoming from the United States Government to put it into effect.

RESOLUTION REGARDING THE TOPOGRAPHIC MAPPING OF THE UNITED STATES

Whereas, The President of the United States has been authorized, by the passage of what is called the Temple Act, which became law on February 27, 1925, to complete the topographic mapping of the United States within the next twenty years, and

Whereas, The completion of this topographic mapping will be of great and permanent advantage and value to many activities of the Government of the United States and of the general public, and

Whereas, Scientific investigations of many kinds involving the welfare of our people depend for their successful conduct and completion on a knowledge of geographical location, elevation and configuration, and

Whereas, Any money spent in topographic mapping should be considered as an investment rather than as a running expense of the Government, therefore be it

Resolved, That the American Geophysical Union expresses great pleasure at the enactment of the bill for the completion of the topographic mapping of the country and hopes that the President of the United States will include in the Budget for the year 1927, to be presented at the next session of Congress, an amount of money sufficient properly to initiate this important work.

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ABSTRACTS OF REPORTS AND PAPERS

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SECTION OF GEODESY

SOME GEOPHYSICAL PROBLEMS

R. L. Faris

Geodetic Operations.—In the beginning of geodetic operations the controlling interest appears to have been to arrive at a more certain knowledge of the exact size and shape of the earth; and, again, to find some exact and reproducible natural unit of linear measure.

The next application of the trigonometric method was in fixing of control points (their latitudes and longitudes) upon which to construct topographic maps of land areas of countries. And, yet a little later on, to hydrographic surveys for charting the sea coasts and connecting waters.

Today the immediate application of geodetic operations finds its practical and economic use for mapping and charting purposes, and in the fixation of international, state, and other boundary lines.

Geodetic Data for Maps and Charts.—The general topographic mapping of the United States has been recently wisely recognized by our National Congress as a project of the Federal Government, to be carried out in a definite period of years.

This project will require, for its proper execution, a more detailed extension of geodetic control over the whole country than exists at the present time.

With this will also come, of necessity, further extension of the lines of precise levels over the country, so that the elevations shown on the maps may also have the proper control, and all be referred to a uniform datum, which is now the generally accepted one of mean sea level.

Importance of Maps and Charts.—It is perhaps here unnecessary to restate the great importance of accurate maps and charts in the commerce and the industrial activities and development of our country, and in the economic utilization of our natural resources. None of these things can be properly considered or initiated without the assistance of topographic maps as a guide in their establishment. From the standpoint of the so-called natural sciences, topographic maps are essential to a clear presentation of many important facts and relations. In comparative biology, for example, the geographic position and elevation are important facts in the classification and arrangement of fauna and flora, just as at sea the configuration of the ocean bottom, temperatures, currents, and the depth of water are essential to a clear understanding of marine life and its development and growth. The geologist must have maps or his geologic surveys and studies cannot be correlated. In fact a

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roster of those who must make use of maps includes those who work in almost every branch of science, industry, and commerce. In this day, maps are an every day necessity. When the importance of maps in the daily life of a nation is thoughtfully considered it is at once seen that the project recently adopted by Congress for the mapping of our country was indeed a wise provision for the public welfare.

Mean Sea Level.—Reference has been made to mean sea level as a datum plane for topographic mapping. The determination of mean sea level is also a fundamental problem of geophysics. Its determination is not the simple problem that a casual view of the ocean surface might lead any one to infer. Mean sea level is a local phenomenon where stations are individually considered, as in the case of its application to topographic mapping. But as a geophysical problem it is found to have variations from year to year, and through a period of years. All of its variations are not yet known nor their causes understood in detail. Therefore, it is yet a problem of prime importance for systematic observation and study.

Velocity of Light, a Linear Measure.—Our unit of geodetic measure is the length of an arbitrary metal bar under certain prescribed physical conditions. The recent experiments of Dr. Michelson in the determination of the velocity of light when carried to further verification and completion give promise of yielding a new method of measuring terrestrial distances which would have a very practical bearing on geodetic operations, especially in regions of difficult accessibility, such as the Alaskan peninsula and the Aleutian Islands. This method for distance measures, together with latitude observations and radio longitude determinations, would greatly expedite the geodetic operations of ascertaining geographic positions in such regions. It is hoped that Dr. Michelson may pursue those experiments to a successful conclusion.

The Standard Spheroid.—I have emphasized the practical applications of geodetic operations more especially, inasmuch as the earlier intent of geodetic work (that of the determination of the size and shape of the Earth) seems now to have been satisfactorily concluded in the adoption of the Hayford Spheroid by the International Geodetic and Geophysical Union. The dimensions of this spheroid will serve all practical purposes for the future; and possibly for scientific purposes as well, as it appears from a study made by Lambert, "that Hayford's Spheroid of 1909, with corrections for topography and isostatic compensation, may be taken as representing our best present knowledge, and it seems probable that future determinations will give nearly the same results.

Isostasy an Established Fact.—For more than half a century the degree of stability of the Earth's crust (the so-called lithosphere) has been a live question for observation, study, and hypotheses. At the last

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meeting of the International Geodetic and Geophysical Union the results of these studies reaped their reward by a definite recognition by that expert international body, of the validity of the theory of isostasy which the late Prof. Hayford did so much to establish as a fact of geophysics.

It would appear that investigators in other lines of geophysics may now study the question of the application of the fact of isostasy to their problems, inasmuch as isostasy does tell us of certain subcrustal conditions that could not be so definitely arrived at in any other way. It seems proper to inquire if their theories should not now be revised so as better to harmonize with the known facts of isostasy. This will require an alteration in the accepted views concerning certain aspects of some of the geophysical sciences. Nevertheless the facts of isostasy must now be reckoned with, and no longer denied their rightful place in the consideration of the mechanics of the Earth's crustal evolution.

Gravity Observations on Land and Sea.—Gravity observations have now been satisfactorily carried out at sea by Dr. Meinesz of the Dutch Geodetic Commission by using pendulums on board a submarine. It is most desirable that many more gravity observations be made at sea in order that more certain knowledge may be had of the isostatic condition of the Earth's crust under the vast ocean areas. While the observations of Meinesz gave good results yet it seems to be of importance to devise if possible some instrument and method which will give the required results with less effort of observation and computation, so that the determinations of gravity at sea may be expedited, and the amount of needed data may be increased more rapidly and to the desired extent.

On land, the gravity determinations, in addition to furnishing data for the determination of the shape of the Earth and for isostasy investigations, also have useful applications in other branches of geophysics, and in the exploration of our natural resources. It is desirable, therefore, that instruments for gravity determinations may be simplified to the end that more data may be obtained with less use of time and effort than is possible with our present apparatus and methods.

Variation of Latitude.—In view of recent theories regarding the Earth's crustal movements, the purposes for which the variation of latitude stations were established have since taken on a new significance. The observations at these stations, in conjunction with the proposed world belt of radio longitude determinations, should in time yield data sufficient to enable us to evaluate the probability of the truth of such hypotheses. Should such crustal movements be found to exist, we may then find the need to revise our ideas concerning a number of the phases of geophysical problems including the variation of latitude itself, in the event that such crustal movements should be found to have an element of periodicity in them. The carrying out of the radio longitude

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determinations and the continuance of the variation of latitude observations give much promise of definite results of value aside from their prime astronomical purposes.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE NATIONAL TIME SERVICES OF THE WORLD

J. C. HAMMOND

This paper gave the results of recent time determinations made at the U. S. Naval Observatory with two instruments and the comparisons by means of wireless signals of the time determinations made at different national observatories during the past two years.

The two instruments were the 6-inch transit circle and a portable transit of 3-inch aperture made by Prin of Paris, each instrument being equipped with an impersonal micrometer. The same stars were observed each night on both instruments and the transits were recorded on the same chronograph so that the comparison was not affected by any errors in the star places nor by any lag of relays.

The monthly mean differences, in the sense Prin minus 6-inch, are:

Month	Difference in clock corrections	No. of nights	Month	Difference in clock corrections	No. of nights	Month	Difference in clock corrections	No. of nights
1922	s		1923	s		1924	s	
Nov....	+0.001	10	Aug...	+0.030	10	May..	+0.004	8
Dec.....	+ .005	9	Sept...	+ .011	10	June..	+ .011	8
1923			Oct....	+ .013	12	July..	+ .025	12
Jan.....	+ .006	11	Nov...	+ .001	12	Aug...	+ .030	6
Feb.....	− .015	8	Dec...	− .003	11	Sept...	− .010	6
Mar.....	− .002	12	*1924*			Oct....	+ .002	8
April...	+ .010	11	Jan....	− .012	10	Nov...	+ .028	7
May....	− .007	12	Feb...	+ .002	11	Dec...	+ .016	6
June....	− .026	8	Mar...	+ .009	10	.....	.....	.....
July....	− .001	9	April..	+ .008	11	.....	.....	.....

The close agreement between the two instruments indicates that the fluctuations which occur in radio time comparisons can hardly be attributed to instrumental errors in determining the time.

The wireless time signals from Annapolis and those from Bordeaux, France, are now received regularly at Washington, Paris, Greenwich, and Ottawa, so that we have a continuous daily comparison of the time determinations made at these four observatories.

The comparisons of the time determinations made at the Naval Observatory with those at Paris, Greenwich, and Ottawa, in so far as they were available, are:

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Period	W—P from Bor. signals	W—P from Ann. signals	W—Gr from Ann. signals	W—Ott from Ann. signals
1922				
Nov. 1–15	+0.11	.....	−0.06	+0.04
" 16–30	+ .12	.....	− .05	+ .10
Dec. 1–15	+ .10	.....	− .01	+ .05
" 16–31	+ .08	.....	− .05	+ .01
1923				
Jan. 1–15	+ .08	.....	− .05	− .12
" 16–31	− .01	.....	− .04	− .06
Feb. 1–14	− .03	.....	− .01	− .01
" 15–28	− .06	.....	− .01	− .05
Mar. 1–15	− .15	.....	+ .02	− .08
" 16–31	− .07	.....	− .02	− .02
Apr. 1–15	− .04	.....	+ .04	.00
" 16–30	.....	.....	− .06	− .02
May 1–15	.....	.....	− .05	− .02
" 16–31	.....	.....	− .07	− .02
June 1–15	.....	.....	− .02	.00
" 16–30	.....	.....	+ .01	+ .02
July 1–15	.....	.....	− .11	.00
" 16–30	.....	.....	− .07	.00
Aug. 1–15	.....	.....	− .15	.00
" 16–31	.....	.....	− .04	+ .04
Sept. 1–15	.....	.....	− .10	+ .01
" 16–30	.....	.....	− .07	.00
Oct. 1–15	.....	.....	− .08	+ .01
" 16–31	− .02	.....	− .15	− .04
Nov. 1–15	.....	.....	− .14	.00
" 16–30	.00	.....	− .03	+ .02
Dec. 1–15	+ .05	.....	.....	− .02
" 16–31	+ .03	.....	− .04	− .04
1924				
Jan. 1–15	+ .02	.....	− .04	.....
" 16–31	+ .01	−0.09	− .06	.....
Feb. 1–15	− .06	− .16	− .04	.....
" 16–29	− .04	− .16	− .01	.....
Mar. 1–15	− .04	− .13	− .03	.....
" 16–31	+ .11	− .13	− .04	.....
Apr. 1–15	+ .12	− .14	− .01	.....
" 16–30	− .02	− .11	− .09	.....
May 1–15	− .03	− .14	− .13	.....
" 16–31	− .06	− .15	.....	.....
June 1–15	+ .02	− .18	− .11	.....
" 16–30	− .11	− .19	− .14	.....
July 1–15	− .08	− .18	− .17	.....
" 16–31	− .10	− .20	− .12	.....
Aug. 1–15	+ .02	− .18	− .11	.....
" 16–31	.00	− .14	− .07	.....
Sept. 1–15	+ .01	− .11	− .04	.....
" 16–30	+ .01	− .13	− .01	.....
Oct. 1–15	− .03	− .15	− .05	.....
" 16–31	+ .07	− .19	− .05	.....
Nov. 1–15	+ .09	.....	− .10	.....
" 16–30	− .01	− .20	− .06	.....
Dec. 1–15	.....	− .12	− .06	.....
" 16–31	.....	− .08	− .03	.....

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The comparisons of Washington with Paris and Greenwich indicate a seasonal variation with amplitude of about 0ˢ.1. By comparing the two columns headed W—P, it is evident that there are fluctuations of 0ˢ.1 or more, which must be attributed to causes inherent in the reception of the signals. The comparisons between Washington and Ottawa show little variation during the last nine months of 1923.

U. S. Naval Observatory,
Washington, D. C.

GEODETIC INSTRUMENTS FROM THE VIEWPOINT OF THE PHYSICIST

LEWIS V. JUDSON

In connection with my work at the U. S. Bureau of Standards in the calibrating of various geodetic instruments and in the preparing of occasional specifications for instruments of this sort as well as in consequence of my visit to European standardizing laboratories I have become deeply interested in this subject. As I have been fortunate in my opportunities for seeing and working with geodetic instruments in several countries, a brief critical description of a few of these may be of some interest. A discussion of these leads naturally to some remarks on geodetic instrument design, and then to a brief outline of the efforts being made in the Section of Length Measurements at the Bureau of Standards to cooperate in geodetic work.

The apparatus used in the standardizing of base line tapes is different in the different countries. (Illustrations of these comparators which were shown as lantern slides will be included in a more detailed paper which it is proposed to prepare for publication.) The apparatus used at the Bureau of Standards is in its essential features the Woodward apparatus with several important changes made in it, in order to enable it to be used efficiently as a laboratory rather than a field apparatus. The five-meter bar, which is kept in melting ice when in use, has been standardized many times and its length is now known to be constant to a high degree of precision.

Several years ago it was my privilege to see the tape-standardizing installations at the Geodetic Survey of Canada and at the Topographical Surveys Laboratory, both located in Ottawa. The apparatus at the Canadian Geodetic Survey Laboratory is similar to that at the U. S. Bureau of Standards; that at the Topographical Surveys Laboratory is a specially designed Geneva Society instrument. A similar comparator is at Belgrade, and while at Geneva in 1923 I was shown a third one with several improvements made for the Swedish Government. A specially designed 4-meter invar standard is used. The instrument is

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capable of rapid use, but requires careful attention to the standardization of the four-meter bar.

The geodetic tape comparator at the International Bureau of Weights and Measures near Paris is of considerable interest, as many tapes for the geodetic surveys of various countries have been standardized there. Provision has been made for securing a new comparator, as the present one is not suited to the demands of precision required in modern geodesy. The base or distance with which tapes are compared consists of reference marks on plates firmly attached to the wall of the building.

Throughout Europe four-meter bars are used quite generally as the basis for geodetic standardization. The Russian Government possesses the most elaborate and precise comparator for standardization of four-meter bars in the world. In a test of this apparatus with Professor Blumbach at the factory of the Geneva Society when it was constructed, I found many excellent features of the instrument. Rigidity, precision and convenience of operation are three of these qualities.

The museums of Europe contain much material showing the development of instrument making. Apparatus of the early days of hand filing, of constructing instruments from plates and from blocks of metal, and of elaborate tracing and carving attract the attention.

The modern geodetic instrument must embody the best construction, using the methods of the best machine and instrument shops and taking advantage of all the resources of our scientific laboratories. The materials of which the instruments are to be made need to be carefully selected in order that those with proper physical properties may be used. The possibility of a wider use of the interferometer should be kept in mind. The method of finishing of those parts which must move freely, and many other points must be carefully considered.

Plans are now under way whereby the Length Section of the Bureau of Standards will be in a position to co-operate in a number of ways in geodetic work. The work of standardizing the base line tapes and of making necessary investigations and improvements in the graduation and calibration will continue. A study of the materials used in making tapes is also in progress. A new field is that of angle measurement, the Bureau now being in possession of an instrument especially designed for the calibration of graduated circles. Later, when a high-precision circular dividing engine is received, we shall be in a position to aid by undertaking investigations in circle graduation and by furnishing such special graduated circles as the manufacturers do not care to handle. The materials suitable for use as instrument circles will also be studied.

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In this study of geodetic instruments I have so far merely outlined our problems. The problems themselves are still ahead and the solutions can only be obtained by co-operation.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

THE NETWORK OF PRECISE TRIANGULATION AND LEVELING OF NORTH AMERICA WITH SPECIAL REFERENCE TO USE IN TOPOGRAPHIC MAPPING

C. V. Hodgson

I wish to present briefly a progress report on the present status of our national horizontal surveys, using for purposes of illustration a lantern slide which represents the first order control established by the United States Coast and Geodetic Survey and other organizations.

It is expected that by next autumn the Coast and Geodetic Survey will have completed two large projects upon which it has been engaged for a number of years. This diagram shows the system of first order triangulation and traverse as we expect it to be at the end of the coming field season. The first large project, a co-operative one between the Coast and Geodetic Survey and the Geodetic Survey of Canada, is the execution of a belt of first order control spanning the international boundary and extending from Lake Superior to the Pacific Ocean. The Geodetic Survey of Canada is executing the section from the 109th meridian to the Lake of the Woods, and the Coast and Geodetic Survey the remainder. This first order control is connected at frequent intervals with the third order triangulation of the International Boundary so that the boundary surveys will be strongly tied in to the basic surveys of the two countries. It has taken four years to complete this project, because of the very difficult conditions of the terrain. The western end crosses very rugged country where transportation of the field parties is by pack train only. Along part of the northern Minnesota boundary the transportation was by canoes and back-packing, while on the section along Rainy Lake and Lake Namakan, first order traverse was run over the ice in mid-winter, with an average temperature while taping of −5° F.

The second project would perhaps be more properly called the general plan for the initial development of first order control west of the 98th meridian. Of the belts of triangulation shown on the sketch we shall have completed, during the field seasons of 1925 and 1926, the western end of the 49th parallel along the northern boundaries of Idaho and Washington, the cross belt extending across eastern Washington

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from Oregon to the International Boundary, the arcs across South Dakota, Wyoming and Montana from the 98th to the 111th meridian arcs, the arc from Needles, California, to the vicinity of Salt Lake and the short arc from near San Antonio westward to the Rio Grande. As you see, the western half of our continent is thus divided up into blocks of from 200 to 400 miles across. With this general plan completed, we are now in a position to bridge in a few months, by triangulation or traverse, any of these areas between triangulation belts, and thus in a single season's work be able to establish final adjusted geographic positions over any area west of the 98th meridian.

The timeliness of our arrival at this preliminary goal is apparent when we consider the import and scope of the Temple Act, passed by the last Congress, which provides for the completion of the fundamental topographic map of the country in twenty years. To complete the topographic map it is necessary first to complete the various grades of control over the country. In order to provide for a proper development of the remaining horizontal control the Federal Board of Surveys and Maps is considering a plan under which each of these areas lying between the existing belts of first order control will be systematically developed with the required amount of first, second and third order control. Coincident with the prosecution of this plan it will be necessary further to subdivide the three or four large areas in the east which still are lacking in first order control. While much remains to be done, it is gratifying to see a long-cherished plan gradually reaching fulfillment.

In this progress report, I have anticipated the probable action of the Board of Surveys and Maps which is considering the adoption of a new system of nomenclature for the various grades of horizontal control surveys. Prior to 1921 the words primary, secondary and tertiary were used to designate the three upper grades of triangulation, in order of accuracy. In 1921, the representatives of the Federal map-making bureaus composing the Board of Surveys and Maps agreed upon the terms precise, primary, and secondary to designate the three higher classes of control. Since this has led to confusion, it is now proposed to adopt the terms first, second and third order which, it is believed, will be self-explanatory and which will be closer in accord with international usage. The reports of the committee of the Section of Geodesy of the International Geodetic and Geophysical Union, on standards and nomenclature for the various grades of triangulation, are not to be presented until the next meeting at Prague in 1927, but we trust that the terminology recommended by that committee will not differ greatly from that which the Federal bureaus here will adopt. At any rate, the ex-

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pected increase in geodetic surveying in this country, under the provisions of the Temple Act, made it inadvisable to delay longer in selecting terms which would be more easily understood.

U. S. Coast and Geodetic Survey,
Washington, D. C.

PRECISE TRIANGULATION AND TRAVERSE

W. F. Reynolds

The adjustment of the arc of precise triangulation, beginning at Puget Sound in the northwestern United States, extending northward along the coast of British Columbia to Dixon Entrance, Alaska, and thence through southeastern Alaska to Skagway, has now been completed up to about latitude 57° in Frederick Sound, Alaska. This is one of the cooperative schemes of triangulation being carried out by the Geodetic Survey of Canada and the United States Coast and Geodetic Survey. It is planned to complete this adjustment within the next year, and then it will be possible to put all the triangulation of southeast Alaska on the North American Datum.

On account of the difficulties encountered, the adjustment of the precise triangulation of the United States has been somewhat retarded in the last few years. In the early days of the Coast and Geodetic Survey the adjustments were very simple, the work being caried ahead directly, there being no fixed positions to be held. The Transcontinental arc and the Eastern oblique arc, while very large arcs, presented no serious difficulties, as the adjustments were made in sections, only the lengths of the measured bases being held.

But when the triangulation became so extensive that loops were formed, discrepancies in latitude and longitude arose. According to our methods, the work first adjusted was held fixed, and the discrepancies distributed in the portion of the loop last completed. This sort of adjustment, while making things consistent, was not fair to the new work, for although as good as the old work it necessarily caught large corrections to make it fit in properly.

As more and more loops were closed the situation became worse, the new arcs receiving much larger corrections than their accuracy justified. It was first proposed to readjust all the precise triangulation and precise traverse of the United States in one piece, holding only the measured bases and Laplace azimuths, and the geographic position of Meades Ranch, Kansas, which is now the initial for the North American Datum. This would probably be the ideal way to make the adjustment, but when it was considered that it would mean the formation and solution of about 3,500 normal equations, the plan was abandoned.

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Major Bowie, Chief of the Division of Geodesy of the U. S. Coast and Geodetic Survey, suggested and outlined, about a year ago, a general plan for the readjustment of the triangulation which it is believed solves our problem. Dr. O. S. Adams, at the request of Major Bowie, investigated the plan and devised a practical method of making the adjustment. Under this plan the discrepancies in loop closures are distributed by a method similar to that used in the adjustment of a precise level net.

The method may be described in general as follows: At each of the junction points of the various arcs a length and azimuth of a line is held fixed. If there is no measured length at the junction, a weighted mean of the various lengths determined by carrying the measured lengths of the nearest bases through the observed angles, is adopted. If no Laplace azimuth is available at the junction, the weighted mean of the various azimuths obtained by carrying through the nearest Laplace azimuths by the most direct route, using the observed angles, is adopted. The only geodetic position held in the adjustment is that of Meades Ranch. Using this position as a starting point, preliminary positions are computed and the best available positions of the junction points of the arcs are determined.

The differences of latitude between the various junction points are considered as observations and weighted inversely as the distances. The discrepancies in loop closure for latitude are then adjusted in the same manner as the adjustment of trigonometric leveling is made. In the same manner the discrepancies in loop closure for longitude are made.

In this way, at each of the junctions of the various arcs of triangulation we have a line fixed in position, length and azimuth, so that as many computers can be put on the adjustments as there are arcs between junction points.

It is the present intention to readjust all of the precise triangulation in the United States west of the 98th meridian by this method. Later it may be necessary to apply the same method to the triangulation in the eastern part of the country.

As this method was suggested by Major Bowie, Chief of the Division of Geodesy of the U. S. Coast and Geodetic Survey, it will be known hereafter as the Bowie method of adjustment for an extensive net of triangulation.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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GEODETIC ASTRONOMY AND GRAVITY

C. H. Swick

Most of the recent astronomic work by the Coast and Geodetic Survey has been done in the western part of the United States and the work this year will also be west of the 98th meridian. Quite a large part of this work is in preparation for the proposed readjustment of the triangulation net of the western part of the country, in order to furnish more accurate data for the junction points.

During the past three years the wireless method has been used very successfully for longitude determinations. We now have twenty-six wireless longitudes. Several minor improvements have been made in the apparatus and methods, and changes are still being made, especially in matters of standardization and simplification of the apparatus and in making it more rugged against transportation shocks.

In addition to the usual office astronomic computations during the past year, an important publication by Miss Sarah Beall giving complete data for all astronomic stations in the United States has been completed and printed and will soon be ready for distribution. It is Special Publication No. 110.

As far as field gravity work is concerned we have been principally marking time during the past year, because of the great promise of Dr. Wright's new gravity apparatus and the possibility that Prof. Michelson will be able to perfect his new "interfergravometer." We have made only two gravity determinations since a year ago, one at Pasadena at the request of Dr. Millikan, and the other on Mt. Wilson at the request of Professor Michelson. Prof. Michelson, at the suggestion of Major Bowie, used one of the gravity pendulums as a time-piece for his new determination of the velocity of light, as he considered it the most accurate time-piece he could obtain for the purpose.

Two other pieces of co-operative work should be mentioned, one a gravity determination at Oberlin College made by Prof. L. W. Taylor, head of the Physics Department, using an apparatus loaned to him by the Survey, and the other a gravity determination at the University of Buffalo made by Prof. Edward Moore, using an apparatus borrowed from Cornell University which will be standardized for him at the base station here.

The Coast and Geodetic Survey has undertaken to compute the topographic and isostatic corrections for the sea stations determined by Dr. Meinesz of the Netherlands. The computations have already been made for about a dozen stations in the Indian ocean and show the isostatic anomalies to be very close to zero, especially over the deep part of the ocean. Near Ceylon and the southern tip of India, the anomalies are

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larger and negative in sign but the isostatic anomalies at several land stations in the southern part of India as computed by the Trigonometrical Survey of India, have the same negative tendency.

At the meeting at Madrid of the International Geodetic and Geophysical Union the Chairman, Major Bowie, proposed that, if any countries wished to have the isostatic reductions made for their gravity stations and could not well undertake the work themselves, they request the Coast and Geodetic Survey to take charge of the work for them. Already, Spain and the Netherlands have asked for estimates, Spain for about 40 stations and the Netherlands for about 50. The work will be done by mathematicians of the Survey working after office hours.

Although quite a large number of gravity stations in various parts of the world have now been isostatically reduced, the distribution of these stations is not as wide as is desirable. There are practically none in the southern hemisphere. To meet this need the Philosophical Society of Washington has made a grant of $100 and the isostatic reductions for five gravity stations on the New Hebrides Islands are now being made by mathematicians of the Survey, working on outside time.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE VARIATION OF LATITUDE

WALTER D. LAMBERT

The work of reducing the observations made at the three remaining international latitude stations has been, since September, 1922, under the direction of Prof. H. Kimura who has recently published preliminary results.

There is a serious gap in the definitive reductions of the international stations; these have been published only through 1912. The Reduced Geodetic Association among Neutrals, which was formed to keep alive scientific geodesy during the World War, has devoted its remaining resources to the completion of these reductions. These resources having proved inadequate, the Section of Geodesy of the International Geodetic and Geophysical Union, as the successor organization, has accepted the obligation to make up the necessary sum. The work will be under the very competent direction of Prof. Wanach, of the Prussian Geodetic Institute.

The international latitude station at Charjui in Russian Turkestan had been lost since the early days of the World War but it now appears that work was continued there until May, 1919, and that the records are safe. They will doubtless be turned over to Prof. Wanach.

The problems of the variation of latitude are far from being com-

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pletely solved. If the earth were absolutely rigid, its free period would be ten months and not fourteen. This lengthening of the period gives us a means of estimating the elasticity of the earth but, on account of irregularities in the observations, we do not know to a day just how long the 14-month period is nor do we know just how much of the lengthening is due to the yielding of the ocean water by flow rather than to the elastic yielding of the solid portion of the globe.

Then we should like to know also why the free period is not damped out by friction. Jeffreys showed that internal friction, large enough to account for the otherwise unexplained apparent secular acceleration of the moon would very promptly damp out the free oscillation; he also found enough oceanic tidal friction to account for the moon's motion, and concluded that internal friction in the solid part of the globe must be small; nevertheless we cannot think of the free oscillation as absolutely unattended by frictional resistance, although there is no clear observational evidence.

The most important question in latitude variation, particularly in secular or quasi-secular variation, is that of crustal movement. The observations of the International Latitude Service make it clear that there have been changes in latitude beyond what can be explained by the known annual and 14-month terms, changes such as to suggest a small quasi-secular shifting of the pole, or else crustal movements. After study I came to prefer the hypothesis of quasi-secular shift of the pole as affording the most satisfactory explanation of the observed latitudes of the International Service. The general problem of crustal movements was discussed only incidentally. Kimura's recent results tend to confirm my opinion. Those who would attribute quasi-secular changes in latitude to crustal movements are not agreed as to which one of the international stations had done most of the moving. All the remaining stations are, however, in country that, on geological or seismological grounds, is at least open to suspicion of instability.

No satisfactory solution is to be had unless we can determine crustal movements by evidence independent of the astronomical latitudes, or unless we increase the number of our astronomic stations and locate them in comparatively stable regions. We could probably get the most valuable results for the least money by reoccupying Charjui and Gaithersburg.

Latitude determinations by the zenith telescope are dependent on star places. The advantage of having all stations on the same parallel is that they can use the same observing program. Corrections to the star placed can be determined from the observations themselves. These corrections are important in various astronomical problems; for instance, they affect the determining of the sun's motion through space.

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The international stations are not the only ones where perplexing changes of latitude have occurred. Rome has apparently changed its latitude by 1.43″ since 1855. A systematic study of such anomalies would be highly desirable. Some of the great observatories are making special studies which will doubtless help us to answer some of our questions, especially in regard to the free oscillations and other oscillations suspected but not proved. Almost any observatory having a good meridian circle could help by conducting a series of absolute determinations of latitude which ought also to be useful in preparing star catalogues.

In one aspect, and that one the most important in the popular mind, namely the climatological aspect, these shiftings of the pole or these crustal movements are insignificant; but from other geophysical points of view the importance of these problems is evident.

The whole subject may perhaps be fitly summed up by enlarging the application of a remark made over 100 years ago by Delambre, but quite as true as when it was uttered:

"The questions of the size and shape of the earth and of the variation of latitude which so long have taxed the skill of mathematicians, astronomers and geophysicists, seem by their very nature to be inexhaustible."

U. S. Coast and Geodetic Survey,
Washington, D. C.

PROJECTIONS FOR MAPS

New Conformal World Maps Derived from Elliptic Functions

OSCAR S. ADAMS

This paper gave a short resume of the history of the subject under consideration, and then a number of slides were shown to illustrate what had previously been done along this line and to show what recent advances have been made in this type of conformal mapping. The slides were the important part of the presentation; the full theory and the analytical development have been published in Special Publication No. 112 of the U. S. Coast and Geodetic Survey, entitled, "Elliptic Functions Applied to Conformal World Maps."

In 1864, H. A. Schwarz, of Halle, pointed out that a circle could be mapped conformally in a regular polygon of n sides by means of the integral

$$w = \int_0^x \frac{dx}{(1-x^n)^{2/n}}$$

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The same thing was shown by Weirstrass of Berlin in 1866.

In the report of the Superintendent of the U. S. Coast and Geodetic Survey for 1877, C. S. Peirce, at that time an Assistant in the Survey, published an account of such a projection which he called the quincuncial projection of the sphere. This was the first conformal projection depending upon elliptic functions that was computed and constructed for geographic purposes.

In the ninth volume, second series, 1887, of the Annales Hydrographiques, Lieut. E. Guyou published the theory of a related projection which, however, was derived in an entirely different manner.

Both the quincuncial projection and that of Lieut. Guyou depend upon the lemniscate integral, which is the Schwarz integral with n equal to 4. These two projections for geographic maps are the only ones with which we are acquainted that have hitherto been computed with elliptic funtions as basis.

The author has made computations for a number of new projections depending on the Schwarz integral, several of which are based on this integral with n equal to 3. The publication No. 112 gives a development of the theory of the functions derived from the inversion of this integral. From the properties of these functions the formulas are developed for the direct computation of the co-ordinates of the various projections. Projections of this kind are associated with a rhombus that becomes a square in case n equals 4. For this reason the name of rhombic projections has been given to this general class of world maps.

In the 70th volume of Crelle's Journal, H. A. Schwarz mentioned the possibility of mapping an ellipse conformally on a circle. This statement suggested the idea that the process might be reversed and that a circle might be conformally mapped on an ellipse, or that the sphere coud be mapped in the boundary of such a figure.

In all, nine new projections were shown, some for the whole world, others for a single hemisphere only. Of the eleven projections of this kind, ten of them have been produced by the U. S. Coast and Geodetic Survey.

U. S. Coast and Geodetic Survey,
Washington, D. C.

SECTION OF SEISMOLOGY

ENHANCING THE VALUE OF THE SEISMOGRAM

FRANCIS A. TONDORF

The Section of Seismology of the Geophysical Union appears satisfied that the number of seismic stations in the United States is adequate. It also feels that, though the installations at these stations are not, in

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every instance, of a class "A" character, nevertheless all could broadcast data of a valuable nature. In the catalogue of Dr. Wood, Bulletin No. 15 of the National Research Council, i. e., Vol. II, Part 7, twenty-nine observatories are listed, and of these scarcely thirty per cent make any pretense at the issuance of regular reports. The value of these grams, assuming that these stations have their instruments in operation, can be enhanced in the marking of them. Possibly the directors of these plants need to be impressed with the truism that this is a "worth while" issue. Now to the stations rendering reports. One of the first problems of the seismologist is to establish the geography of earth tremors.

Epicenters are best figured out from the times of arrival of the first and second preliminary tremors. How have our grams been measuring up to these times? This may be best noted in a concrete case. The figures are taken from the files of the Georgetown University Seismological Observatory. These files show that in the past nine years 739 quakes have been registered, an average of 83 per annum. Registrations from mechanically recording instruments only are here considered. This establishes a fairer comparison with the other stations in the States, where, for the most part, this type of instrument is in operation. Reading these 739 grams along all three components, i. e., East-West, North-South, and the Vertical, we find that the first preliminary tremor was recognized and its time of arrival read in 556 instances. Of these P is listed in just 100 cases as appearing with a marked on-set, that is, iP. P is catalogued as showing up with an emergence 376 times and as a very questionable wave in 80 cases. On the assumption that the most and probably the only dependable reading is P with a marked on-set, we have, as far as P is concerned, the low figures of 14 per cent for the determination of focal points of quakes. Added to this is the fact that these figures drop considerably because, in not a few instances, iP is mistaken for PR or iS. P as an emerging wave gives P too late. A systematic comparison of photographically registered quakes with those mechanically recorded unquestionably shows this. Where P is masked in microseisms, the tendency is persistent to anticipate the time of P. Now for S. The total number of cases in which this wave's time was read as appearing with a marked on-set was 94 out of the 739 quakes registered. This is 11.4 per cent of the total and 2 per cent below iP. The total reading for S was 360. This low reading, as compared with total for P, is readily explained in that many of the quakes were from very distant points. Taking iP and iS at their maximum appearance as the most dependable data for epicentral determinations, we have at most twelve per cent of the total data available. It is true that where either P or S is entirely obliterated from the gram, there eL may be

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substituted for either. But as eL is the more difficult of reading, the error is proportionally greater. The conviction is entertained that a critical analysis of the records of other stations in the States would not only run these figures a close second, but would show them far below; this because the data from our station show the comparative study of grams from three different types of seismographs—a unique condition. All this bespeaks, so it is inferred, weakness in a one-man interpretation. Is there any salvaging these grams? It was suspected at one time that much might be gained by comparing readings of grams from different stations. Confidence was lost in this method because of prejudice for or against the opinion of another.

And this is, at best, but a shifting of the difficulty. A Central Bureau, as suggested by Klotz some years ago, appeals to the writer as the one effective solution of the problem. Klotz fancied it feasible to request stations to transmit all grams to the bureau for evaluation and comment. We are not convinced that this procedure is the most prudent. It might lead stations to suspect that they would thereby forfeit their autonomy. Let the stations be invited to despatch into the Bureau their interpretations with the original grams and the grams returned with such annotations as may appear helpful for future interpretations. The Bureau would thus have the benefit of the gram as interpreted by its committee. This would be salvaging much material hitherto rated as worthless. Thus wise, too, the reliable would be placed in competition with the certain. Much would so be learned, also, regarding the effect of position of instruments, the instruments themselves, etc., on the inscriptions. Anomalies would be transmuted into laws. As seismograms are only an asset to the literature of geophysics when expressed in absolute units, standardization of instruments is imperative. Authority for such standardization should be vested in some bureau. This body should see that all instruments should have their constants fixed on a common basis, rated at stated intervals, etc. The grams then would take on much additional value.

Once the seismogram is thus lifted in value it will become a *deus ex machina* to solve more of the mysteries lurking within the crust of the planet on which man breathes and moves.

Georgetown University, Seismic Station,
Washington, D. C.

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SEISMOLOGICAL WORK OF THE COAST AND GEODETIC SURVEY

N. H. Heck

Specific authority to engage in seismological investigation was granted to the Coast and Geodetic Survey on January 31, 1925. Under existing conditions no funds are available for the fiscal year ending June 30, 1926, but in spite of this there has been and will be considerable activity. The activity includes the placing of the work at the magnetic observatories, where it has been secondary, on an equal basis with the magnetic work, and also taking over the activity heretofore carried on by the Weather Bureau, including publication.

An earthquake on February 23 and that in Eastern Canada on February 28, called attention to the need for the entry of the Coast Survey into the field. Attention was called to the difficulty of certain geologists and the press and public in locating this earthquake, several geologists placing it under the Gulf of Maine. Need for a central organization for evaluation of earthquake results was indicated. The February 28 earthquake will be discussed in a report by the Canadian Government, with the co-operation of the Coast and Geodetic Survey, which has received 600 reports of visible and felt effects. These reports show that it was more severely felt in the direction towards Iowa than in the direction towards Virginia.

Information regarding existing seismological observatories throughout the United States has been obtained. Several of the stations are very good and others very indifferent, both as to equipment and attention paid to the work. All are needed to secure complete information, but it is important that two or three should be completely equipped and careful study made of the results. The Coast Survey will concentrate for the present on Tucson, Arizona, a station of peculiar value, since it is near, but not in, the California region. Utilization of results is being given attention, also the avoidance of overlapping and duplication. Fault map was discussed, with the statement that the Coast Survey would not attempt for the present to map epicenters.

Reasons for the Bureau taking up this work were given, including: close relation in methods with magnetic work; carrying on of geodetic surveys in earthquake regions; collection of information in regard to tidal waves; presence of vessels in regions where earthquakes have occurred and may occur; and completion of surveys so that changes due to further earthquakes may be accurately measured; experience in study of seismograms. Surveys of special interest in this connection are those of Monterey Bay, California, where there is a submarine valley with

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steep sides, and the examination of ocean deeps off Mexico and Central America by the *Guide*.

The present aim includes: maintenance of popular interest in program; co-operation with existing agencies in collecting earthquake information and scientific investigation of earthquakes, based on the best possible records of high-grade instruments. An Anderson seismometer is being installed at Tucson to replace the worn-out Bosch-Omori instrument.

Value of position of magnetic observatories, which are in all cases near the coast, was pointed out as being of special value for the study of under-sea earthquakes.

Need for seismologists to exercise patience in appraising the progress of the Bureau was emphasized and a promise of steady progress was made.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE INTERPRETATION OF THE SEISMOGRAM

HARRY FIELDING REID

The first thing to be determined on the seismogram is the time of arrival of the several groups of waves. In connection with data on the time and place of the shock recorded we construct the transmission curve. Although the form of this curve is fairly well known at present it is by no means very accurately known. It serves two important purposes, to locate the origin of earthquakes when not otherwise known, such as submarine shocks or those occurring in uncivilized regions; and it helps to explore the interior of the earth. If the ratio of the elasticity to the density changes suddenly at some depth below the earth's surface, the velocity of transmission will change there and we should expect a slight sudden change in the tangent of the transmission curve. Earlier claims of surfaces of discontinuity were based on supposed changes of the above type; but the accuracy of the transmission curve was not sufficient to yield reliable results.

A new method has been developed, namely, the study of the intensity of the record at various distances from the origin, the differences being due to reflections and refractions at surfaces of discontinuity. Wiechert and his colleagues and the Mohorovicics have given attention to this method and the existence of surfaces of discontinuity in the earth is becoming better and better founded. A great complication arises from the fact that either a longitudinal or a transverse wave will in general at a surface of discontinuity give rise to waves of both types in both media, so that four waves are developed moving with different velocities

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and in different directions and each of them must make its mark on the seismogram when it comes to the earth's surface.

The break in the transmission curves at 100° to 120° from the origin has long been known; Wiechert explained it by the existence of a surface of discontinuity. There still remains much work to be done in this field. The method is clear: we must follow the various waves theoretically, and by a careful comparison of the theoretical results with observation we must eliminate errors and confirm truths. The subject is difficult, but not hopeless; and its successful prosecution will do two things: it will explain the characteristics of the seismogram and will teach us much about the interior of the earth. There is no way except by means of earthquake waves of feeling out the earth's interior.

In the report on the California earthquake of 1906, it was shown that the transmission curve of the surface waves, regarded as a straight line, did not pass through the epicentre. This is fairly self evident, for the surface waves must be started by the arrival of the longitudinal or the transverse waves at the earth's surface; and, although these would reach the surface first at the epicentre and might start surface waves there, other surface waves would be started by oblique body waves in front of the former; therefore, the front of this group would originate at some distance from the epicentre. It seems probable that the transverse waves originate the surface waves, for the first phase is quite distinct in nearby earthquakes, but the second phase and the surface waves cannot be separated; moreover, the transverse waves have greater amplitudes than the longitudinal.

As our observations become more accurate we see that the seismogram is very complicated. The mathematicians taught us that there should be body waves and surface waves in a limited elastic medium, and some seismologists tried to find them in the seismogram. Oldham finally succeeded. Thus, by the aid of the mathematicians we may look forward to continued progress in unraveling the secrets still hidden in the seismogram.

The Johns Hopkins University,
Baltimore, Maryland.

SECTION OF METEOROLOGY

A POSSIBLE MEANS OF SAMPLING THE HIGHER ATMOSPHERE

W. J. HUMPHREYS

A few years ago it was widely believed that beyond the level of the highest clouds, or limit of vertical convection, temperature varies but little with height. This belief was based on the fact that in these higher

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reaches of the atmosphere the flux of earth radiation is substantially the same at all levels. Furthermore, sounding balloon records greatly strengthened this idea, by showing that in middle latitudes the temperature of the atmosphere is around −55° C. all the way from the top of the highest clouds, say 10 to 12 kilometers above the surface, up to the greatest height attained, 30 to 35 kilometers.

In 1923, however, Vegard argued, from auroral observations, that at great heights, such as 100 kilometers, the temperature of the air is down at least to −225° C.; while Lindemann and Dobson reasoned, from observations of meteors, that beyond the level of 40 to 50 kilometers the temperature of the air must be approximately 30° C.—tropical heat!

Here, then, was confusion as to the temperature of the upper air; and the confusion was as bad, or worse, in regard to the presence at these levels of helium and hydrogen. The situation seemed to demand the unanswerable testimony of direct observations. This demand is not now so urgent as it was, since the evidence in favor of the excessively low temperature of the outer air has been refuted, and that for its high temperature seriously questioned. Nevertheless, we still are without direct and unquestionable knowledge of the state and composition of the higher atmosphere.

A possible general scheme for obtaining these data is as follows:

1. The height will be attained with a rocket of, say, the Goddard type.

2. A hermetically sealed vacuum bulb, surrounded by water and ice to give a constant temperature, as per device used by C. G. Abbot on balloon pyrheliometers, is carried by the head of the rocket.

3. At the top of the flight the tip of a tube drawn out from the vacuum bulb is broken off, and, as soon as the bulb has filled, again sealed up—a scheme used by Teisserenc de Bort.

4. As the tube is being filled a flash light is set off; on a cloudless night, of course, during the dark of the moon.

5. From two or more suitable stations this flash is photographed among the stars, giving a parallax from which the height is readily computed.

We have, then, the temperature, 0°C., and height, at which the bulb was filled, and, as soon as it is recovered, the pressure of the gas in it at this temperature, hence the pressure at the time and place of filling, can easily be determined in the laboratory. Finally, gas analysis will furnish the composition of the captured air.

From a series of such samples, taken at various levels, the temperature distribution is readily found.

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Given a suitable rocket, now being developed, the investigation, though requiring skill and ingenuity, certainly is both feasible and worth-while.

U. S. Weather Bureau,
Washington, D. C.

BROADCASTING WEATHER REPORTS FROM THE PACIFIC AND JAPAN BY THE UNITED STATES TO FRANCE

E. B. CALVERT

As indicating the foundation already laid for international exchange of radio weather reports the following facts are presented.

The Imperial Observatory at Kobe, Japan, broadcasts three or four times daily weather reports from about twenty stations in Japan, the Philippines, Manchuria, Korea and a few places in China. A similar service is performed by the Philippine Weather Service at Manila. Broadcasts are also made from Honolulu which include reports from two or three places in the Hawaiian Group, including Midway Islands, and certain stations in Alaska and continental United States.

The most extensive broadcast for the Pacific is that made by the U. S. Weather Bureau through the naval radio station at San Francisco at 9:30 a. m. and 7:30 p. m., local time. Major bulletins are broadcast at those hours on 7,000 meters wave length. These bulletins contain reports from nine stations in Alaska, two in British Columbia, three in the northwest Canadian Provinces, thirty in continental United States, Manila and Guam and from eight other places in the Far East. In all fifty-four stations are included in this broadcast. Vessel reports from the Pacific, when and as received, are also included in this broadcast.

So far as the United States is concerned no attempt is made to collect any Far Eastern reports by radio.

Reports from the Far East are collected in that region and forwarded by radio in a message addressed to the U. S. Weather Bureau, to San Francisco, thence to Washington, D. C., by land wires.

Radio exchange of weather reports between France and the United States has been in progress for some time through the U. S. Naval station at Annapolis and the radio station at Lyons, France. Since the present schedule between these two stations is already approaching the overloading point, the inclusion of additional reports covering the Pacific area would have to be taken up and considered broadly by the two countries directly interested.

U. S. Weather Bureau,
Washington, D. C.

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METEOROLOGICAL OBSERVATIONS BY AIRPLANES

W. R. Gregg

In the last year of the World War, and in the year following, some 550 observations of temperature and humidity were made in northeastern France by the British Meteorological Section, R. E. The data were used currently in forecasting and were later summarized in an important paper by Capt. C. K. M. Douglas of the British Meteorological Office.

This type of free-air investigation has been continued in Great Britain, a recent report stating that some 300 observations were obtained during the past year. The heights reached are usually about three kilometers, in some cases considerably greater. These heights are determined by means of an altimeter, corrected for air temperature.

Similar observations are made in France, Belgium, and other European countries. In all cases the results are used in forecasting, and in some instances they form the basis for free-air studies. The data themselves have not, however, been published in detail.

In this country meteorological observations in airplanes were first made by the Signal Corps in co-operation with the Weather Bureau at Aberdeen Proving Grounds in 1918. Air density at different heights was computed from the records of pressure and temperature and used in connection with bombing tests. The results were not entirely successful, owing to difficulties in mounting the recording instrument in such a way as to provide good ventilation and at the same time avoid excessive vibration. Nevertheless the data were very useful.

During the Summer and Autumn of 1923, the Weather Bureau, cooperating with the Air Service of the War Department, made several measurements of dust content at different altitudes up to 10,000 feet in airplanes. The relation between dustiness and visibility was studied, and the results were published in the Monthly Weather Review for March, 1924.

Since the war, the aerological section of the Bureau of Aeronautics, Navy Department, has made quite a large number of these observations at its air stations near Norfolk, Pensacola, San Diego, and elsewhere. A particularly interesting series of records was obtained at San Diego during the latter half of 1924. The flights reached one and a half kilometers on the average, and some went as high as two and a half kilometers. The time required was from one-fourth to one-half hour. In addition to the automatic records of pressure, temperature, and humidity, detailed notes were made of weather conditions in general, including particularly the occurrence of fogs and clouds, and heights of the latter, both bases and tops, when measured. Observations of wind

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speed and direction were made at the same time with pilot balloons. The data from San Diego are telegraphed to the District Forecast Center of the Weather Bureau, at San Francisco, for use in forecasting.

More recently, during the past month in fact, April, 1925, the Bureau of Aeronautics and the Weather Bureau, co-operating, have undertaken to secure daily, except Sunday, observations in airplanes at the Naval Air Station, Anacostia, D. C. Some of the details have not yet been completely worked out, but in general the plan is to have a flight made at about 8 a. m., so that the data may be available for the forecaster by 9 or shortly thereafter. The plane will "level off" at certain altitude intervals, in order that instrumental lag may be eliminated; the precise altitudes have not been finally selected, but there will probably be four or five in a 3-kilometer flight, one being quite close to the ground and the intervals progressively increasing with height.

Upon the completion of each flight the pressure, temperature, and humidity at certain levels will be quickly computed and telephoned to the forecaster at the Weather Bureau. Height and thickness of cloud layers, when measured, visibility and any other condition of unusual interest will be included.

It is believed that the carrying out of this program will mark the first step in bringing about a desirable and a very effective change in free-air exploration. The use of kites has given us a great deal of valuable information and has up to the present time been the most satisfactory method for this type of investigation in the lower levels. But kites have serious limitations. In the first place, they cannot be used in calms or in very light winds. Again, they cannot be used in or very near populous centers, where means of quick communication are available. Most serious, however, is the fact that the flights require considerable time so that the data, although of great value in research, cannot be communicated to the forecaster quickly enough to be useful in making his forecasts. The current use of the data has therefore been impossible. This will not be true in the case of airplanes, and therein lies their great advantage. In addition, the data secured can be used later in researches just as are those from kites at the present time.

It would seem that, at flying fields of the War and Navy Departments and perhaps others where flights are made regularly, it should be possible through co-operative arrangements to have free-air observations made with little added cost, and there would thus be established a system of observing stations covering the entire country, the data from which would be of direct and immediate benefit to aviation and, more important still, would increase the accuracy of general weather forecasting.

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This is the program which we hope will eventually grow out of the arrangements recently made between the Bureau of Aeronautics and the Weather Bureau.

U. S. Weather Bureau,
Washington, D. C.

A FORM OF SIMPLIFIED CALENDAR

C. F. MARVIN

The speaker presented orally the latest information that had come to him from a consideration of the subject by a committee of the League of Nations. At the last meeting of that committee (in February, 1925) a definitive step was taken, viz, an agreement was reached on the part of various ecclesiastical authorities to fix the date of Easter, probably at a date early in April. Favorable action was not taken on the 13-month calendar. General comments were made on the several aspects of the subject.

U. S. Weather Bureau,
Washington, D. C.

PRINCIPLES ON WHICH WEATHER FORECASTS IN THE UNITED STATES ARE BASED—AN ILLUSTRATIVE EXAMPLE

ALFRED J. HENRY

The Madrid meeting of the Section of Meteorology adopted a resolution expressing the wish that the Central Meteorological Service of each country should illustrate by an example the methods on which its forecasts are based.

The day selected should be September 25, 1923, * * * and each country should set out the forecasts for its own area and should relate them to the general situation prevailing over the continent to which that area belongs in such manner as to bring out the scientific principles on which the forecasts are based.

Pursuant to the foregoing resolution, the forecasters in charge of the five forecast districts into which the United States has been divided for forecast purposes, were asked to report upon the methods on which they had made the forecasts for their respective districts on the date specified. These reports have been received, summarized and a copy of the summary and accompanying documents is ready for transmission to the International Secretary of the Section.

The speaker presented the facts above to the meeting and pointed out that each forecaster recognized in the pressure distribution on the

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date in question—the position and intensity of cyclones and anticyclones—the dominant control of the weather during the ensuing twenty-four to thirty-six hours. No warm or cold fronts were present, but cognizance was taken of the tendency of cyclones and anticyclones to pursue certain paths at this season of the year.

The influence of topography in causing up and down slope winds was recognized in making the forecasts for the western third of the country.

It was further pointed out that the day selected, September 25, was not calculated to bring out either precepts or principles of weather forecasting in the United States not already well known, and it was suggested that a day in the cold season would better serve to bring out the information that evidently was desired. The suggestion was not adopted.

U. S. Weather Bureau,
Washington, D. C.

EFFECTS OF CHANGES IN SOLAR RADIATION ON THE EARTH'S ATMOSPHERE

H. H. CLAYTON

The studies made by me in regard to the effects on the earth's atmosphere of changes of solar radiation as measured by the Smithsonian Astrophysical Observatory indicate that these changes have an appreciable and important influence on the earth.

In general it may be said that an increase of solar radiation causes a decrease of pressure in the equatorial regions, a rise of pressure in middle latitudes and a decrease of pressure between the 60th and 70th parallels. The increase of pressure in middle latitudes shows a seasonal change, being greatest over the continents in winter and over the oceans in summer.

A third variable which comes out distinctly is the latitude displacement of the belts of high and low pressure ordinarily found in the atmosphere. With a largely increased solar radiation (one or two per cent above normal) there is found a marked excess of pressure in high latitudes over the continents in winter and over the oceans in summer. As the solar radiation decreases, the belts of excess pressure are displaced toward the equator and with very low values of solar radiation are found between the equator and 20° N. These systematic displacements follow both short and long period changes in solar radiation. With the short period changes there is in addition a wavelike progress toward the east.

Excesses and defects in temperature and precipitation are intimately

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related to the excesses and defects of pressure. With large changes of solar radiation the temperature in the center of the North American continent may change as much as 40° F.

Chief Forecaster (Retired),
Argentine Weather Service.

SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

THE ELECTRIC CONDITION OF THE LOWER ATMOSPHERE

S. J. Mauchly

Our knowledge regarding the electrical conditions of the lower atmosphere has increased so greatly during the last two decades that it is in order to take stock, as it were, of the atmospheric-electric data now available for investigational work.

While potential-gradient records extending over a considerable number of years are available for various European stations, series of continuous observations from other parts of the globe are not only few in number but, in general, they extend over shorter periods and lack adequate control. Further, many large regions are represented solely by observations obtained at temporary field stations or in connection with special expeditions; such observations obviously serve to give only a general notion of the value of the gradient and are extremely inadequate in the matter of giving reliable indications of the daily and annual variations. Too frequently, however, the value of such data is still further diminished by the lack of adequate control observations for reducing the observational results to absolute values. Now that the general magnitude of the Earth's electric field is well known, there is less and less need for short series of uncontrolled variation observations and an ever-increasing need for extended series of well-controlled observations.

It appears unlikely that the problem of the origin of the Earth's charge can be solved on the basis of the present very general knowledge alone, and we shall need, doubtless, to know much more about the distribution and time variations of the Earth's field than can be gotten from the data now available before such solutions as may be put forth can be definitely rejected or accepted. Only the most carefully controlled observations in many representative and widely separated regions will suffice to determine whether the Earth's undisturbed field varies, let us say, with latitude, or in any other systematic way, or whether its

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average value is the same the world over. Similarly, the variations during the day, year, and sunspot cycle must not only be known for more and better-distributed stations and for longer periods of time, but every source of spurious variation must be eliminated if dependable results are to be forthcoming to suggest new methods of attack and to test new theories.

When we come to matters dealing with the ionization of the air, it is, of course, realized that only the bottom of the atmospheric ocean is available to us for observation and experiment, and in our use of such data this should always be borne in mind. It remains to point out that if our generalizations regarding the Earth's field are founded on rather meager data, this is true in even greater degree as regards atmospheric ionization. Again, as in the case of the potential gradient, reliable data are exceedingly scarce. In fact, although there are at present more observatories obtaining continuous records of the atmospheric conductivity than ever before, the total number is only five, namely, two in Europe, one in North America, one in South America, and one in Australia. It may be of interest to note that the average values of the conductivity at Washington appear to differ very little from the published values for Potsdam, although different methods are used at these stations. However, preliminary values indicate that at Watheroo (Australia) the average conductivity is at least double the Washington value and that at Huancayo (Peru), at an altitude of 11,000 feet, it is five or six times the Washington value, essentially identical equipment being employed at the three stations last named. Since these observations are all accompanied by simultaneously obtained records of the potential gradient, it is obvious that much valuable information will result from a comparison of the air-earth current densities at these five widely distributed stations. Valuable as the results promise to be, however, they leave much to be desired, especially in the matter of distribution with latitude and it is hoped that other stations, especially in regions lacking such observations, will be able in the near future to supplement the observations now under way.

Investigations for determining the causes of the ionization in the atmosphere are being assiduously prosecuted by numerous observers both in Europe and America. Observations of the atmospheric conductivity and ionic density made aboard the *Carnegie* in the various oceans show that the values of these quantities at sea do not differ much from average land values, although concurrent observations aboard the *Carnegie* show that the radioactive content of sea air well removed from land is entirely inadequate to maintain the ionization there observed. Similarly, while the ionization in closed vessels has been and still is

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under investigation from various points of view, the results to date afford no satisfactory answer regarding its true relation to the ionization of the air.

Department of Terrestrial Magnetism,
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Washington, D. C.

PRESENT STATUS OF RADIO ATMOSPHERIC DISTURBANCES

L. W. Austin

Our knowledge concerning atmospheric disturbances is still very meager. In addition to the well-known relations between disturbance intensity and wave-length, time of day, season of year, etc., it is now recognized that a large number of disturbances come from definite centers, such as mountain ranges, rain areas, and thunderstorms, that a considerable portion are oscillatory in character, though some are of the nature of untuned pulses, and it is also thought that atmospheric crashes are sometimes heard simultaneously at stations thousands of miles apart.

The origin of the ordinary rumbling disturbances (grinders) has been the subject of many conjectures. Some have supposed that they might come from above and be caused by electrons shot into our atmosphere from the sun. Others have held that they can all be explained as due to the lightning in thunderstorms in various parts of the world, while still others believe that in the lightning flashes the discharge is generally too gradual to produce powerful radiation and that the atmospherics are largely due to some as yet unknown form of dark discharge which occurs not only in connection with thunder-clouds but in other air movements quite unconnected with thunderstorms. In this connection, Professor C. T. R. Wilson has shown theoretically that there may be discharges from thunder-clouds to the conducting regions of the upper atmosphere.

According to Mr. Watson Watt, radio-compass observations show that in Europe only about one-third of the atmospheric centers are connected with thunderstorms, but that about seventy-five per cent are associated with rain areas of some kind. Captain Bureau of the French Meteorological Office has collected data covering a period of many months which show a close relationship between the atmospherics in France and the advance of meteorological cold fronts.

In the United States the disturbances along the Atlantic seaboard appear to come pretty regularly from the southwest, while on the California coast the centers seem to lie among the mountains not far back

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from the ocean and seem to be nearly fixed in position giving very sharp atmospheric directions. In the center of the country, observations at Madison, Wisconsin, by Professor Terry, indicate that the directions are variable, depending on thunderstorms, rain areas, etc., very much as in western Europe.

For the more convenient study of disturbance direction, Mr. Watt has designed a direction recorder which consists of a slowly rotating radio-compass coil, the shaft of which carries a drum on which a syphon recorder marks the disturbance crashes.

Mr. Watt, in collaboration with Professor Appleton, has investigated the wave form of the atmospherics, using a cathode-ray oscillograph (Braun tube). The main disturbance is found to be of audio frequency, usually aperiodic though sometimes showing slight oscillation. Some of the curves show high-frequency ripples on the main wave. These may be the real atmospherics, as it seems doubtful whether the slow-period main oscillation would be capable of producing the observed disturbing effect.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

APPLICATION OF RADIO TRANSMISSION PHENOMENA TO THE PROBLEMS OF ATMOSPHERIC ELECTRICITY

J. H. Dellinger

While there is no novelty in the idea of inter-relation between the problems of radio transmission and of atmospheric electricity, nevertheless recent radio developments indicate definite hope that radio phenomena will shed considerable light on the things with which the student of atmospheric electricity concerns himself. The application of the radio phenomena to these problems is application to the underlying rather than to the immediate problems of atmospheric electricity and terrestial magnetism. Radio gives direct means of conducting controlled experiments on phenomena affected by the electrical conditions of the atmosphere, a means which is wholly impossible in the field of direct atmospheric-electric measurements. These means are being abundantly used. We are learning to select radio wave transmissions in particular directions, at particular times, and on particular frequencies, such as to produce an effect conditioned in a definite way upon electrical conditions in the atmosphere. Organization of such work is proceeding from the sporadic work of the individual to organized effort on a large scale.

After much study of the available data and consideration of possible

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causes, radio science now considers that the major phenomena of radio wave transmission have their origin in the stratosphere.

While weather conditions are not entirely without effect on radio phenomena, the weather-radio phenomena are less definite and less certainly proved than the phenomena associated with atmospheric electric conditions.

Rapidly accumulating radio evidence has thoroughly established the hypothesis proposed by Eccles in 1912, which explains the greater distance of radio transmission at night by the daytime ionization of the air caused by the ultra-violet light in the sun's rays. The removal of this cause of ionization at night clears up the lower atmosphere so that the waves can penetrate to high altitudes at night. At some level in the atmosphere there must be a pressure so low that the permanent ionization above this level will render the medium conducting, thus providing something of the nature of a surface along which waves can glide at night. Turbulence near this surface explains fading. A theory definitely worked out by Larmor during the past year has more firmly established this theory by showing that the effect of the interaction of the radio wave with the ionized particles leads to a bending down of the waves, thus establishing a calculable quasi-refraction which gives a real physical picture of the wave transmission, and is a great advance over the conception of a wave sliding along a hypothetical conducting surface. This theory, with recent additions of the effect of the earth's magnetic field, enables a determination of the approximate height in the atmosphere of levels of various degrees of ionization from the observed effects of radio transmission in terms of the frequency, times of day, and other known factors of the transmission. Radio thus provides a tool with which we can actually explore these strata and determine their electrical properties.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

ON THE SUPPOSED CONDUCTING LAYER IN THE ATMOSPHERE AND THE EFFECT OF THE EARTH'S MAGNETIC FIELD IN RADIOTELEGRAPHY

G. Breit

The Earth's magnetic field has been shown recently to be a probable cause of the peculiarities of radio transmission. This important discovery has been made by Nichols and Schelleng[1] as well as by Appleton

[1] *Bell System Tech. J.*, p. 215, April, 1925.

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and Barnett [2] more or less as a sequel to Larmor's important paper on wave propagation.[3] The exact mathematical theory of the effect of the Earth's field is, of course, a too detailed matter to be discussed here. The fundamental principles, however, are simple. According to Larmor's theory the bending of radio waves is brought about by the presence of free ions and electrons in the upper atmosphere. The presence of these ions affects the phase velocity of the waves and makes the velocity greater at increasing heights. As a result, the wave-front turns while traveling in the upper atmosphere and bends around in such a way as to strike the ground ultimately.

This theory of Larmor's supposes that every electron or ion vibrates along the direction of the electric intensity of the incident wave. The effect of the magnetic field is to exert a force on the moving charged particle which is perpendicular to its direction of motion and to the magnetic field, and thus turns the direction of motion out of the line of the electric intensity of the wave. This results in a rotation of the plane of polarization of the wave and also in a change in its velocity of propagation. The propagation along the Earth's magnetic field is described best of all in terms of the circularly polarized waves into which one may imagine the incident wave to be analyzed. These two waves have different velocities of propagation and, therefore, are refracted differently. It is shown by Nichols and Schelleng that while one of the waves may be refracted towards the Earth the other may be refracted away from it. In other cases the two waves may be simply arriving with different intensities.

By Larmor's theorem the motion of an electron under the action of a magnetic field is the same as it would be if the magnetic field were absent and the motion were referred to a rotating frame of reference, the frequency of rotation being $\frac{e}{4\pi mc} \backsimeq 3 \times 10^6$ per second. This is seen to lie at about 100 meters wave-length. A more exact analysis shows that the critical wave-length of transmission is located at about twice this value.[4]

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[2] *Elec.*, No. 2446, p. 398, April 3, 1925.

[3] *Phil. Mag.*, 48, p. 1025, 1924.

[4] It may be shown that the differential equations $a\ddot{x} = E_x + \frac{1}{c}(\dot{y}H_z - \dot{z}H_y)$, $a\ddot{y} = E_y + \frac{1}{c}(\dot{z}H_x - \dot{x}H_z)$, and $a\ddot{z} = E_z + \frac{1}{c}(\dot{x}H_y - \dot{y}H_x)$, where $a = m/e$, which are the equations of motion of an electron of charge e, mass m, have the following solution which corresponds to the case of forced vibrations, the frequency of E_x being $\omega/2\pi$:

$$(x, y, z) = \frac{a^2\omega^2\vec{E} - \vec{h}(\vec{h}\vec{E}) + i\omega a[\vec{h}, \vec{E}]}{a\omega^2(h^2 - a^2\omega^2)}, \quad \vec{h} = \vec{H}/c$$

arrows indicating vectors and the symbols ( ) and [ ] standing for scalar and vector products, respectively. This makes the critical value of ω lie at h/a as stated (*Cf.* reference 2 and 3 above).

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Both on this theory and on Larmor's one may expect the arrival at any point on the Earth's surface of two or more waves. This consequence has been investigated experimentally by Appleton and Barnett[5] who obtained evidence of waves arriving with large path differences in this way. Similarly the data of Pickard in this country offered evidence of the same nature as has been pointed out by the author.[6]

Another consequence of such a view of radio transmission must be true. It is easy to see that if the transmission takes place over two independent paths then interrupted continuous waves must arrive as two sets of interrupted waves rather than one. This effect is now being searched for at the Department of Terrestrial Magnetism with the cooperation of the Radio Corporation of America. No definite effect of the described character has been found. If this effect is absent, we may be forced to attribute more of the erratic character of radio to the effect of the Earth's magnetic field than we have been doing so far. It may be, for example, that the combined action of a partially conducting Earth and the magnetic field will give rise to complicated effects similar to interference.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THEORETICAL CHANGES OF THE MAGNETIC ELEMENTS WITH ALTITUDE

LOUIS A. BAUER

Confining our attention to the portion of the Earth's magnetic field—about 94 per cent for 1922—which may be expressed by a potential due to a system of magnetic and electric forces below the Earth's crust, the theoretical variation of any intensity component, C, with altitude, a, above the Earth's surface may be expressed by the following simple formula, in which terms containing higher powers of a than the first are for the present neglected:

$$\delta C_a = -3\frac{a}{R}\cdot C_o \qquad (1)$$

Here R=Earth's mean radius=6,370 kms. and C_o is the value of the particular intensity component at the Earth's surface. We may use with sufficient accuracy the approximate formula:

$$\delta C_a = -\frac{1}{2}aC_o\times 10^{-3}, \qquad (1a)$$

hence a decrease of about one two-thousandth part of C per kilometer elevation above the Earth's surface.

[5] *Nature*, March 7, p. 333–334, 1925.
[6] New York meeting of American Physical Society, February 1925.

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Suppose, for illustration, that H, the horizontal intensity, is 0.2 C. G. S., and the vertical intensity, Z, is 0.55, which are the approximate values of these elements at the present time at Washington, then, if a=10 km.=about 6 miles, we have

$$\delta H = -5H_o \times 10^{-3} = -0.0010 \text{ C.G.S.}$$
$$\delta Z = -5Z_o \times 10^{-3} = -0.0027 \text{ C.G.S.}$$

These are quantities that could be detected with our present experimental means, and even for half the altitude, 5 km., or 3 miles, the expected normal decrease, ought to be readily measurable. In these measurements it would be necessary to diminish the effect of the diurnal variation, the precise changes of which with altitude are themselves the subject of investigation; by making the measurements at different hours of the day, preferably early in the morning and late in the afternoon, the effects of the diurnal variation could probably be sufficiently eliminated.

As regards the angular quantities, the magnetic declination and inclination, it may be seen readily from formula (1) that these should *theoretically* suffer no changes with altitude.

Just what the effect on the magnetic elements with height is of the other portions of the Earth's magnetic field—the external potential (about 3 per cent) and the non-potential part (also about 3 per cent)—cannot as yet be definitely stated. There are certain indications from magnetic observations made at various levels during solar eclipses and from the diurnal-variation phenomena of atmospheric electricty that there may be comparatively low-lying systems of electric forces which might play an important part in the determination of the changes in the magnetic elements even in such regions at present accessible to us by airplane or dirigible.

In general, the results from observations on mountain tops would indicate a more rapid rate of decrease in the magnetic intensity than that which formula (1a) indicates. The criticism can, of course, be made legitimately that the results from such observations may contain effects due to possible local magnetic disturbance. It is, nevertheless, gratifying to have a summary of observations made on mountain tops, such as Mr. Hazard will give in his report.

It is also of interest to note here that such observations as have been made during balloon ascents, as for example, those by James Glaisher in England in 1864, indicated a diminution in the horizontal intensity with altitude. Details with regard to the precise manner of making the observations and the rate of decrease are, however, not accessible to me at present.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

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METHODS AND MEANS FOR THE MAGNETIC EXPLORATION OF THE UPPER ATMOSPHERE

J. P. Ault

A study of the forces which cause periodic variations or sudden disturbances in the Earth's magnetic field would be materially aided by a knowledge of how these variations are modified by changes in elevation. The magnetic exploration of the upper atmosphere has been a recognized problem for many years and its solution has become increasingly important with the rapid development of radio communication and the study of atmospheric electricity.

Theoretical considerations indicate that the changes in the absolute values of the magnetic elements with change in altitude are small. Various attempts to determine these changes have been made by observations in mountainous regions but instrumental limitations and local disturbances rendered the results unreliable.

To obtain information of any value for theoretical studies, will call for instruments of high precision because of the smallness of the changes in the magnetic elements and in their variations to be expected with changes in altitude attainable with present methods of aerial exploration. Such measurements must be controlled also by simultaneous observations at the Earth's surface.

Present instrumental equipment could be modified for use on dirigibles and would give results sufficiently accurate for practical navigational purposes. For more accurate results the most promising instrumental development would appear to be in the design of apparatus using electrical methods, with rotating coils and with galvanometers arranged for photographic registration. Such apparatus must be compact and light and suitable for mounting in unmanned carriers, such as kites or sounding balloons, by means of which much higher altitudes can be reached than by aircraft.

Some progress may be expected by observations continuing over a long period and the discussion of second differences in the magnetic variations for land stations situated not far apart but at greatly different altitudes. Such a program is planned for the near future by the Department of Terrestrial Magnetism in connection with its observatory at Huancayo, Peru, at an elevation of 11,000 feet, with temporary observatories at sea-level and an intermediate elevation. The value of such data would be greatly increased if such a program could be carried out at other points on the Earth's surface at the same time. Val-

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uable information is expected also from investigations of radio communication and studies of the transmission of electromagnetic waves through the air.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

ALTITUDE CHANGES OF THE MAGNETIC ELEMENTS AS DEDUCED FROM OBSERVATIONS ON MOUNTAIN TOPS

DANIEL L. HAZARD

Many attempts have been made to determine the change in the Earth's magnetic field with change in altitude by observations on the Earth's surface at different altitudes, some of them more than a century ago. One of the most meritorious of these early attempts was made by Kreil in Austria about the middle of the nineteenth century. A number of others were made in Europe betwen 1891 and 1902. In June, 1918, upon the initiative of Dr. Louis A. Bauer, Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, observations were made at a number of stations in the vicinity of Pikes Peak, Colorado. The work was done jointly by the above department and the U. S. Coast and Geodetic Survey. Four stations were occupied at the top of the mountain at an altitude of 4.3 km. and there were 32 stations at lower levels from 1.7 km. to 3.7 km. The results, particularly the declination values, indicate the presence of local disturbance throughout the region.

The results of these various determinations of changes of intensity may be summarized as follows:

Authority	Locality	Year	No. of stations	Range of altitude	Proportional decrease per km.
				km.	
Kreil	Austria	1850	27	1.34	1:309
Moureaux	France	1891	4	2.25	1:326
Preston	Hawaii	1892	7	4.00	1:150
Sella	Italy	1893–4	2	4.00	1:1000
Van Rijckevorsel and Van Bemmelen	Switzerland	1895–6	?	?	?
Liznar	Austria	1898	205	1.30	1:700
Pochettino	Italy	1899	2	2.10	1:400
Do	Italy	1902	2	2.50	1:500
U. S. C. and G. S. and Dept. of T.M.,C.I.W.	Colorado	1918	29	2.60	1:774

On the basis of the Gaussian potential theory Liznar found that the proportional decrease in intensity should be approximately $3h/H$ or

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1:2124 per kilometer, without change of direction. Tanakadate, in connection with the magnetic survey of Japan for the epoch 1895, derived corrections for altitude from the observed changes in the horizontal plane and obtained approximately the same results as by Liznar's method. The results in the above table agree in indicating decrease in intensity with increase of height, but the rate of change is in every case several times as great as theory demands. Whether these differences are real or are to be ascribed to the effect of irregular distribution of magnetism in the mountainous regions where the necessary differences of elevation are to be found cannot be determined from the data now available, and it is doubtful whether regions can be found where observations may be made with the assurance that the results will not be vitiated by the presence of local disturbance.

[Since the foregoing was written attention has been called to observations made by W. Brückmann in Switzerland in 1909, and by A. Senouque on Mont Blanc in 1906. The former observed at 5 mountain stations and 4 valley stations in the region between Lake Thun and Lake Brienz on the north and the Rhone Valley on the south, and found a decrease of horizontal intensity with increase of height amounting to about 11γ per km., as compared with 10γ per km. to be expected on the basis of the Gaussian formulas. The northern half of the region was mainly limestone formation and apparently free from local magnetic disturbance, and every precaution was taken to ensure the accuracy of the observations, even to the extent of operating a temporary magnetic observatory at Grindelwald during the progress of the field work. Three more southerly stations were evidently somewhat disturbed and were not used in deducing the above result. In the summer of 1906 A. Senouque made observations at 6 stations on the massif of Mont Blanc at altitudes ranging from 550 m. to 4,800 m. He corrected his results for diurnal variation and for geographic position on the basis of a uniform distribution of magnetism over the region involved. He obtained the following changes with altitudes: Dip decreasing 0.5 per km.; horizontal intensity (0.213) decreasing 21γ per km.; vertical intensity (0.398) decreasing 27γ per km.; total intensity (0.452) decreasing 34γ per km. The intensity results show a consistent decrease with increase of height and Senouque was satisfied on that account that the differences were not due to local disturbance, especially as the observations were made either on the ice or on different kinds of rocks.]

U. S. Coast and Geodetic Survey,
Washington, D. C.

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SECTION OF OCEANOGRAPHY

RECENT OCEANOGRAPHIC WORK CARRIED ON JOINTLY BY THE MUSEUM OF COMPARATIVE ZOOLOGY, AND BY THE U. S. BUREAU OF FISHERIES

HENRY B. BIGELOW

Since 1912, the chief field of this joint exploration, still continuing, has been the Gulf of Maine, with the coastal waters to the east and southward to Chesapeake Bay. A general survey has been made of the plankton, as well as of the physical oceanography; while the Bureau of Fisheries is prosecuting a study of the Biology of the important food fishes.

In the winter of 1914, the oceanic triangle Chesapeake Bay-Bermuda-Bahamas, and the Straits of Florida were surveyed oceanographically by the Bureau of Fisheries and the U. S. Coast and Geodetic Survey, jointly. In the winter of 1919-1920, the "Albatross" took observations along the South Atlantic coast and about Cuba.

Problems of special interest are, (1) the extent to which the temperature of the coast water is influenced by currents from the north; (2) the source of the highly saline water of the bottoms of the deeper basins on the Continental Shelf, and (3) the involuntary drifts of pelagic fish eggs and larvæ, and of the plankton.

Since 1922, the Bureau of Fisheries and the Biological Board of Canada, at the suggestion of the North American Committee on Fisheries Investigations, have put out some thousands of drift bottles, with a large percentage of recoveries.

It seems established that the Labrador current exerts only an indirect influence west or south of the Laurentian Channel.

The circulation is shown to be anti-clockwise in the large basins, clockwise around the banks.

The mixture of *banks* and oceanic water along the edge of the continent is of higher density than either of its components; hence sinks; and this so-called "slope water" is pumped into the basin of the Gulf of Maine by a rather steep density gradient.

Probably the draft of Banks water toward the zone of sinking, deflected to the right by the earth's rotation, is responsible for the southwesterly drift over the outer part of the shelf, demonstrated by many of the bottle-drifts.

Salinity, drift bottles, current measurements and the distribution of the plankton, locate the indraught into the Gulf of Maine as in its eastern, the outflow as along its western side. But the dominant drift divides off Cape Cod, part continuing to eddy eastward toward Nova

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Scotia, for many bottles set out off the coast of Maine have been found along western Nova Scotia and in the Bay of Fundy.

The eddying circulation of the Gulf is shown to cause extensive involuntary migrations for most of the important food fishes, causing the fry to take to bottom far from where they were hatched.

Studies of the migrations of the cod, prosecuted by the Bureau of Fisheries during the past two years, have a direct bearing on the problems of circulation.

The work of the International Ice Patrol assumes increasing importance in American oceanography. The taking of serial temperatures and salinites, as well as a plotting of the drift-tracks of individual bergs, is a regular part of the work of the Coast Guard cutters which patrol the Grand Banks, March-July. This has greatly widened our knowledge of the interaction of the Labrador and Gulf stream currents around the Grand Banks. Lieutenant Commander E. H. Smith, who has made the oceanographic observations during the past few years, is now working them up dynamically at the Geophysical Institute in Bergen.

Harvard University,
Cambridge, Massachusetts.

THE SMITHSONIAN INSTITUTION AND OCEANOGRAPHY

AUSTIN H. CLARK

The Smithsonian Institution is the legal repository of the collections brought together by the various governmental agencies. These collections are stored in the United States National Museum. They consist of the various forms of plant and animal life and of samples of the bottom sediments.

In some cases, material resulting from a cruise has been bodily transferred to the Museum, which then becomes responsible for its study and for the preparation of reports upon it. But usually the greater part of it has been distributed, by the agency through which it was collected, to a varying number of specialists who have prepared reports upon it and returned it, after which it has been transferred to the Museum for permanent preservation.

American work in biological oceanography, so far as governmental establishments are concerned, has been chiefly a study of the various types of bottom-living animals. Our explorations have covered an enormous area in the west Atlantic and in the east, central, and north Pacific which at the time we began the work were wholly unknown regions. Naturally, therefore, the work has consisted for the most part of descriptions of the new forms of life and records of various types from different places.

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These descriptions of new animals and the records of their occurrence are embodied in an enormous number of publications, mostly short, which are widely scattered throughout the various zoological journals.

At the present time there is a pause in our activities in oceanographic research so far as it concerns the bottom-living animals, and the Smithsonian Institution realizes the advisability—indeed the necessity—of taking immediate advantage of this interval of calm for collecting and correlating our present scattered and disconnected information on marine types in the form of monographic treatises each of which shall cover a broad field and, complete in itself, shall serve as a starting point for future work.

Monographic work of this type requires the undivided attention of thoroughly competent men covering long periods of time. Such men are not common and cannot be developed from the average student. They must be specially sought for and when found they must be so placed and so encouraged as to be willing to devote an appreciable part of their lives to this exacting and monotonous type of work.

The adequate publication of comprehensive monographs is a matter of very considerable expense, and at present the Smithsonian Institution cannot see its way clear to bind itself to the publication of any given piece of work of indefinite magnitude. There is a possibility, however, that the situation may become easier in the more or less near future.

For some years past the most active work in biological oceanography has had to do with those small and minute forms of life collectively known as plankton. These forms of life are of prime importance, for they include the pelagic plants of various types, especially the diatoms, through the activities of which inorganic matter is synthesized into organic, and the small animals which feed on them and in so doing reassemble the protoplasms contained in the plants into units of such size that they are available as food for larger creatures, directly or indirectly, especially for the fishes, seals and whales.

The study of plankton organisms requires a special technique varying in the different groups. Heretofore it has been localized and for the most part confined to the north Atlantic, north of latitude 42°.

The present Museum staff has been, is, and will be for some time fully occupied in the study of the vast accumulation of bottom animals which has come to it by transfer, exchange and purchase during the past forty years, and just now there are no facilities for handling plankton work.

The Institution, however, realizes the vital importance of this work on account of its bearing on the broader problems of our fisheries; and it further realizes the necessity for a broad plankton survey of the oceans as a whole.

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The Museum has in storage a vast amount of material gathered by the *Albatross* and other ships and as yet unstudied, and it is hoped that the Institution or the Museum will shortly be in a position to make at least a preliminary survey of this material, as well as to get together a series of preparations of plankton organisms which shall serve as a reference collection for plankton studies.

U. S. National Museum,
Washington, D. C.

CONTRIBUTIONS TO OCEANOGRAPHY FROM THE NAVY DEPARTMENT FOR THE YEAR ELAPSED SINCE APRIL, 1924

G. W. LITTLEHALES

According to the precept of the Section of Oceanography that calls for this Report, the coast surveys executed by the Navy Department have not seemed germane to this account, and accordingly, are not embraced herein.

The completion of the continuous record of the tide at Tahiti for twelve months, by automatic gauge supplied by the Navy Department and kept under the supervision of MR. Harrsion W. Smith, late of the Massachusetts Institute of Technology, supplements the existing resources for the study of oceanic tidal behavior in the Pacific.

During the summer and autumn of 1924, the Navy Department Conference on Oceanography laid plans, now continuing in course toward fruition, for national co-operative researches in oceanography, recommending first attention to the Caribbean and Gulf of Mexico regions and the exploration of the tract reaching to the Azores on the one hand, and to the Panama Canal and the Galapagos and Hawaiian Islands on the other.

Naval representatives in co-operation with the Bishop Museum of Honolulu have conducted the *Tanager* expedition to the northwestern islands of the Hawaiian chain and the *Whippoorwill* expedition to the islands between Hawaii and the Equator; also, in co-operation with the California Academy of Sciences, a more recent expedition in the U. S. S. *Ortolan* to the Mexican Islands of Guadalupe and Revilla Gigedo. In each of these expeditions, the collections have been chiefly in the domain of natural history.

Based upon the Bathymetric Chart of the bottom of the Pacific Ocean bordering the coast of California between San Francisco and San Diego, recently issued by the Hydrographic Office, Professor A. C. Lawson has published a discussion entitled "The Continental Shelf off

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the Coast of California," Bulletin No. 44 of the National Research Council, April, 1924.

Navigators, in large numbers, without distinction of nationality, report to the Hydrographic Office concerning the phenomena of the ocean. It is from the accumulations thus gained that useful results have been put at the service of transportation and communication in such publications as the Pilot Charts of the several oceans.

Founded mainly upon the results of magnetic observations contributed by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, the Hydrographic Office has constructed and published, for the epoch 1925, world-charts of the Halleyian lines of the Variation of the Compass, the Inclination of the Magnetic Needle, and the Horizontal Intensity of the Earth's Magnetism.

The Navy is continuing to render aid to the Scripps Institution of the University of California, in a program of oceanographic observations in the Pacific Ocean. Oceanographic and meteorological observations have been made and water and plankton surface samples have been taken between San Diego and Guadalupe Island by the Destroyer fleet. Similar observations and collections are expected to be in course between San Diego and San Francisco, between San Francisco and Hawaii, between Hawaii and San Diego by that part of the Destroyer fleet that returns directly from Hawaii to San Diego, and between Hawaii and Australia by that part of the Destroyer fleet that proceeds to Australia. Before these observations were begun, all of the thermometers used in recording temperatures were calibrated.

Of the fundamental operations in oceanography, one of the most important is sounding the ocean for the purpose of ascertaining its depth and providing graphical representations of the contours of configuration of its basins. The installation of the Sonic Depth Finder in vessels of the Navy has enabled them to sound the sea in the ordinary course of voyaging.

There follows a résumé of soundings thus made during the last year:

U. S. S. STEWART, February, 1924—Line of sounding taken on run from Manila to Hong Kong. New bank discovered with least depth 146 fathoms, west of Luzon. Lat. 17° 30′ N., Long. 118° 30′ E. (approx.)

U. S. S. STEWART, March, 1924—Running survey of a specified area in the China Sea. Lines of soundings taken when searching for a number of reported dangers. Also additional soundings over the bank in Lat. 17° 30′ N., Long. 118° 30′ E.

U. S. S. STEWART, May, 1924—China Sea: Dairen to Yokohama to Shanghai to Amoy.

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U. S. S. STEWART, November, 1924—China Sea: Shanghai along E. coast of Philippines to Lat. 5° 20′ N. and return to San Bernardino Strait.

U. S. S. MILWAUKEE, March, 1924—North and Central America and Mexico.

U. S. S. MILWAUKEE, October, 1924—En route Transatlantic flight ZR-3, N. Atlantic: Soundings taken off the east coast of the U. S. in the North Atlantic Ocean; in the West Indies; off north coast of Cuba.

U. S. S. MILWAUKEE, September, 1924—N. Atlantic—Davis Strait, west coast of Greenland.

U. S. S. CONCORD, February, 1924—Indian and North and South Atlantic Oceans; Port Sudan to Djibouti and Djibouti to Barbera; Barbera to Mombasa to Zanzibar; Lourenco Marques to Durban; Durban to Port Elizabeth; Port Elizabeth to Cape Town; Cape Town to Walfisch Bay; Walfisch Bay to St. Helena.

U. S. S. CONCORD, March, 1924—St. Helena to Pernambuco; Pernambuco to St. Thomas, thence to Vieques Sound.

U. S. S. COLORADO, February, 1924—North Atlantic Ocean—Gibraltar to New York. Colorado Bank discovered in 33° N. 37° ½ W.

U. S. S. CINCINNATI, March, 1924—North Pacific Ocean—off west coast of Mexico near Cape Corrientes.

U. S. S. NIAGARA, December, 1924—Caribbean Sea—La Guaira, Venezuela, and Willemstadt, Curacao, to Gulf of Venezuela.

U. S. S. RALEIGH, October, 1924—North Atlantic—vicinity of Faroe and Iceland.

U. S. S. MARYLAND, March, 1924—North Atlantic Ocean—off coasts of Maryland, Virginia, and North Carolina.

U. S. S. MARYLAND, December, 1924—North Pacific Ocean; off the coast of California in vicinity of San Diego. Unsuccessful search for bank of 50-90 fathoms in 32° 65′ N., Long. 119° 45′ W.

U. S. S. HULL AND CORRY, May, 1924—North Pacific Ocean; soundings taken to discover practical route for cable to be laid between Seattle and Alaska.

U. S. S. CORRY, October, 1924—N. Pacific Ocean; Cape Descanso to Santa Rosa Is. and between San Francisco and Monterey Bay.

U. S. S. HANNIBAL, December, 1924—North Atlantic; Delaware Breakwater to Hampton Roads and from latter place to Key West.

U. S. S. HANNIBAL—North Atlantic, West Indies; Key West to Siguanea Bay, Isle of Pines.

U. S. S. MARBLEHEAD, January, 1925—Southampton to Marseilles, to Algiers; Funchal to Boston.

U. S. S. HULL, February, 1925—Development of Santa Rosa Bank, California.

U. S. Hydrographic Office,
Washington, D. C.

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PHASES OF WORK OF THE CARNEGIE INSTITUTION OF WASHINGTON WHICH CONCERN THE SECTION OF OCEANOGRAPHY

J. P. Ault

That part of the work of the Carnegie Institution of Washington during the past year which is of special interest to the Section of Oceanography was the continuation of the studies in marine biology at the Tortugas Laboratory, Florida, and the interest in deep-sea sounding stimulated by the activities of the Advisory Committee in Seismology of the Institution, already reported by Dr. Littlehales.

During the summer of 1924, ten research workers were present at the Tortugas Laboratory carrying on investigations more or less relating to the biological phase of oceanography, and material was collected for study in connection with the problem of the formation of marine limestones. This station is to be maintained, and important contributions to marine biology are confidently expected from future researches.

The ocean-survey work of the Institution's Department of Terrestrial Magnetism has not been resumed since the completion of the sixth cruise of the *Carnegie* in November, 1921. It is hoped this work may be taken up again soon, the plans calling for a three-year cruise in all the oceans, followed after an interval of three years by a second three-year cruise. This program, if carried out, will greatly enhance the practical and theoretical value of the ocean magnetic and electric work already done, in supplying much-needed secular variation data, and will furnish opportunity to undertake additional investigations having a more direct bearing on oceanography. The intensive program of magnetic work heretofore undertaken will be materially reduced, thus giving time for more work in atmospheric electricity, earth-currents, gravity, radio communication, and deep-sea sounding. A new sonic sounding apparatus, devised by Dr. H. C. Hayes, will be installed, and a systematic and complete series of soundings over the routes to be covered during the proposed cruises, as shown on the accompanying chart, will add much information to our knowedge of the contour and topography of the oceanic basins and will be extremely useful in the study of other oceanographic problems.

Since previous cruises were arranged more with a view to increasing our knowledge of the distribution of the magnetic elements over the oceans, only eighty intersection points were established from which data regarding the secular variation in magnetism may be obtained for all the oceans. The recent discussion by Mr. H. W. Fisk[1] of secular variation

[1] *Terr. Mag.*, vol. 29, No. 4, p. 139-148, December, 1924.

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over land areas, particularly over South America and Africa, has shown the need of additional control from observations at sea. Especially did the discussion show the desirability of knowing the variations over short periods of time. Accordingly, future ocean work is planned to yield the maximum information possible regarding secular variation, and the routes will follow closely the tracks of previous cruises.

The rapid development of radio communication and the study of the transmission of electromagnetic waves around the earth emphasize the need of increasing our knowledge of atmospheric electricity and its variations over the oceans and show the desirability of studying at sea the daily and seasonal effects on the intensity and directional conditions of radio transmission and reception. The researches of Appleton and Barnett of Cambridge and of Nichols and Schelleng of the Bell Telephone Laboratories in this field, as reported in *Nature* of March 7, 1925, show the importance of knowing the atmospheric-electric variations at sea as well as over land. Appleton and Barnett attribute the variation between day and night strengths of signals to ionization due to solar agencies, hence to atmospheric-electric variations, while Nichols and Schelleng state that "the theory (of propagation of radio waves over the earth's surface) now developed takes into account both the earth's magnetic field and the distribution of ionized particles in the atmosphere."

In connection with the Department's study of earth-currents at the Watheroo and Huancayo observatories, it is planned also to make some observations on earth-currents at sea during future ocean work, in an attempt to determine how such currents are modified over the oceans as compared with those occurring over land areas.

It is hoped that some form of gravity apparatus will be developed which will give reliable results at sea so that the determination of the gravity anomalies over the ocean areas may be included in the work of the proposed cruises of the *Carnegie*.

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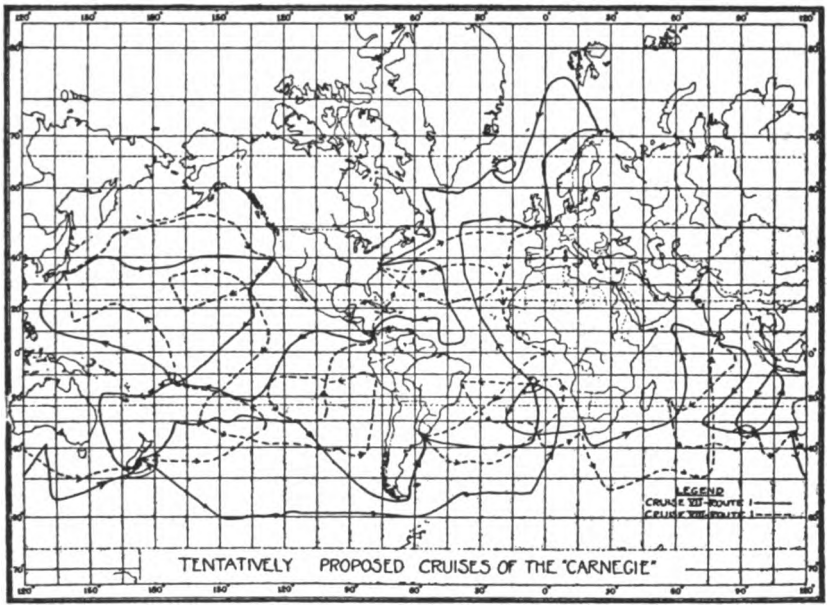
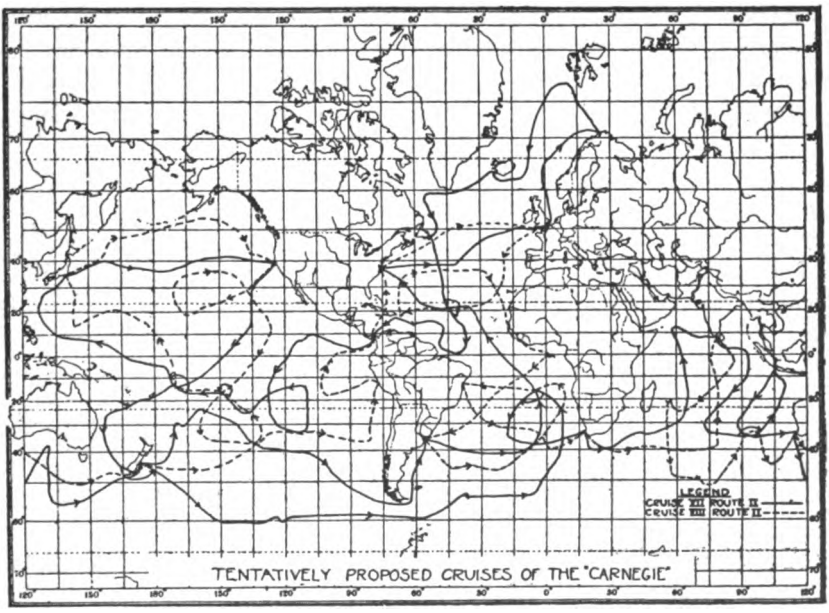


CRUISES TO START FROM WASHINGTON IN DECEMBER



CRUISES TO START FROM WASHINGTON IN JUNE

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

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OCEANOGRAPHIC WORK OF THE COAST AND GEODETIC SURVEY

N. H. Heck

The principal area of work of the Coast and Geodetic Survey in oceanography is the continental shelf of the United States and the regions under its jurisdiction. As this area is important to the oceanographer it is fortunate that while the survey work is carried on to meet the needs of the mariner, the work is done accurately enough to meet the needs of the oceanographer.

The work of the Coast and Geodetic Survey includes: determination of bottom relief, measurements of temperature, collection of water samples at different depths, collection of bottom specimens, the determination of sound transmission through sea water, studies of tides and currents and other activities, which, though primarily covered by other Sections of the Union, extend into the field of oceanography.

A policy in effect during the last three years, of carrying surveys on the Atlantic Coast to the hundred-fathom curve and on the Pacific Coast to the thousand-fathom curve, is bringing highly satisfactory results. The important progress, especially in southeastern Alaska, was shown by means of a chart. In the West Indies a survey of the Nares deep by the *Guide* is an important accomplishment. In the Philippines the work is carried to the thousand-fathom curve and half of the Sulu Sea has been surveyed. It is scarcely necessary to state the value to the oceanographer of having correct knowledge of the sea bottom in the vicinity of the continents and oceanic islands.

Illustrations of the usefulness of accurate surveys include: the difficulties of the Japanese in determining the changes in Sagami Bay resulting from the earthquake of September 1, 1923; lack of knowledge of changes due to the Yakutat Bay earthquake in Alaska in 1899. With modern accurate surveys, changes due to earthquakes can be readily detected. Development of the wide submarine valley in Monterey Bay, California, with no corresponding shore formation, is of special interest.

The cruise of the *Guide* completed a series of cruises between the east and west coasts which resulted in a fairly comprehensive survey of the region adjacent to the route. Two deeps were found off the Coast of Central America and Mexico with a combined length of 625 miles and a maximum depth of 3600 fathoms.

Vessels cruising between Seattle and western Alaska take oceanographic data en route.

Steady progress has been made in the use of acoustic methods for sounding and position finding on the coast of Oregon and Southern California.

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British studies of the velocities of sound check with those given in Publication No. 108, Coast and Geodetic Survey. The acoustic method of sounding may be considered as established, but has certain limitations which will be clearly defined with continued use. A great deal is being learned about the radio acoustic method of position finding and the transmission of sound waves. Maximum distance obtained is eighty-five miles.

Temperatures, water samples and bottom specimens were obtained in each locality in a manner which involves little additional cost to the government. Scripps Institution determines the salinity and examines bottom samples.

With reference to tides, attention is called to the following publications:

Harmonic Analysis and Prediction of Tides, by Paul Schureman; a treatise for the tidal mathematician.

Portable Automatic Tide Gauge, by G. T. Rude (in press). This describes an apparatus which obtains tidal data more economically than heretofore.

The Tides, by H. A. Marmer, (about to go to press); a non-mathematical discussion valuable to the non-tidal oceanographer.

Mean sea level is being studied.

Observations by Dr. Meinesz of the Dutch Geodetic Commission, for determining gravity at sea, made on a submarine, have been reduced by the Coast Survey method. The portion of the Indian Ocean so far studied is in a very nearly perfect state of equilibrium. Work is to continue between Holland and Java by the Panama Canal. A one hundred dollar grant from the Philosophical Society of Washington is going to make possible the isostatic reduction of gravity stations on some islands in the Pacific. The establishment of the physical fact of equilibrium will be of great value in the study of configuration of the ocean beds and the processes which operate to change their elevations.

No magnetic work is being carried on at sea, as that of the *Carnegie* is so superior to that of a magnetic vessel. It is hoped her work can be resumed in the near future.

The *Los Angeles* now carries a ship's type dip-circle of the Coast and Geodetic Survey to study the possibility of magnetic observations in the air.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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SECTION OF VOLCANOLOGY

SUMMARY OF REPORTS OF COMMITTEES

R. B. SOSMAN, *Secretary*

The Secretary reported for the Committee on the Igneous Geology of Yellowstone Park (Cross, Daily and Van Orstrand). Mr. Cross had made an examination of the manuscript left by Arnold Hague intended to be published as Volume I of the Monograph on the Park. He has found the manuscript in much less advanced stage of preparation than has been supposed. It would appear that considerable revision and additional work may be necessary in order to complete the petrographic data. Mr. Van Orstrand has examined the data on spring temperatures and thought that much of this could be prepared for publication. The material consists of about eighty packages of manuscript with many specimens. The report of the Committee was supplemented by Mr. Day who said that some new work on the Hot Springs was being planned by Mr. Allen and himself on behalf of the Geophysical Laboratory. Mr. Jaggar said that he had been an assistant to Hague in the field and that Hague had followed closely Archibald Geikie in his style of presentation and treatment of the subject matter.

Mr. Mendenhall of the Geological Survey stated that Prof. Setchell's chapter on Algae had been released to him for publication if he so desired and that the Hot Spring data, or any other data considered useful, would either be released for the use of the Geophysical Laboratory or would be incorporated with the new work of the Laboratory in some form of publication by the Survey.

The Committee on an International Catalog on Volcanoes had no report. Mr. Jaggar stated that Sapper's catalog had been published in the Zeitschrift für Vulkanologie and also in the Proceedings of the Strasbourg Society.

The Committee on Hot Springs (R. B. Sosman and Kirk Bryan) reported that the 1923 symposium on Hot Springs had been published. There had also been discussion with members of the Weather Bureau concerning the possibility of correlating variations of Hot Spring temperatures with rainfall and air temperature. Some manuscript data on western springs had been obtained from the Weather Bureau. Mr. H. T. Stearns supplemented this report by statement that Miss N. E. Dowell's bibliography of Hot Springs in the United States was being mimeographed and was to be distributed for corrections and additions.

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OF THE
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November, 1926 Number 56

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SEVENTH ANNUAL MEETING, APRIL 29 AND 30, 1926
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Vol. 11, Part 2 November, 1926 Number 56

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GENERAL

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STATUTES AND BY-LAWS OF THE AMERICAN GEOPHYSICAL UNION

(As amended to 1926)

PREAMBLE

The American Geophysical Union is hereby established by the National Research Council. It supersedes the "American Section of the proposed International Geophysical Union." The American Geophysical Union is the American National Committee of the International Geodetic and Geophysical Union and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The American Geophysical Union is constituted as follows:

ARTICLE 1

Objects

(a) To assist in carrying out the objects of the International Geodetic and Geophysical Union, which are: To promote the study of problems concerned with the figure and physics of the Earth; to initiate and co-ordinate researches which depend upon international co-operation, and to provide for their scientific discussion and publication; and to facilitate special researches, such as the comparison of instruments used in different countries.

(b) To promote and co-ordinate the study of the various branches of geodesy and geophysics in the United States of America and its outlying territories.

ARTICLE 2

Membership

The membership of the American Geophysical Union shall be as follows:

(a) Those who composed the membership of the "American Section of the proposed International Geophysical Union" on July 1, 1919.

(b) Those who may be appointed by the Executive Board of the National Research Council upon nominations submitted by the Executive Committee of the American Geophysical Union.

(c) The Chairman of the Division of Foreign Relations, the Chairman of the Division of Physical Sciences, the Chairman of the Division of Chemistry and Chemical Technology, the Chairman of the Division of Geology and Geography, and the Chairman of the Division of Biology and Agriculture, of the National Research Council, members *ex officio*.

(d) The American officers of the International Geodetic and Geophysical Union and of its Sections, members *ex officio*.

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ARTICLE 3

Sections

The American Geophysical Union shall be divided into Sections, in accordance with the organization of the International Geodetic and Geophysical Union, as follows: (a) Geodesy; (b) Seismology; (c) Meteorology; (d) Terrestrial Magnetism and Electricity; (e) Oceanography; and (f) Volcanology. The members shall designate the Section, or Sections, to which they will belong. The *functions of the Sections*, in their respective fields, shall be the promotion of the objects of the American Geophysical Union.

ARTICLE 4

Officers of the American Geophysical Union

The *Officers of the American Geophysical Union* shall consist of a chairman and a vice-chairman, elected to serve for a period of three years, and not to be eligible for immediate re-election to their respective offices; and a general secretary, to serve for a period of three years.

ARTICLE 5

Officers of Sections

The *Officers of the Sections* of the American Geophysical Union shall consist for each Section of a chairman, a vice-chairman, and a secretary, whose eligibility and periods of office shall correspond to those of the Union. The Chairman of each Section shall have the power to appoint, with the right to vote, a representative of the Section to such meetings of the Executive Committee of the Union as he may be unable to attend.

ARTICLE 6

Executive Committee

The *Executive Committee* shall consist of the chairman, the vice-chairman, and the general secretary of the American Geophysical Union, and of one representative from each of the sections of the Union, who shall be the chairman thereof or a member appointed by him; and, in addition, *ex officio*, the American officers of the International Geodetic and Geophysical Union, and of its Sections, the chairman of each of the Standing Committees of the American Geophysical Union, and the chairman of each of the following Divisions of the National Research Council: Foreign Relations, Physical Sciences, Chemistry and Chemical Technology, Geology and Geography, and Biology and Agriculture. This Committee shall have charge of all administrative matters of the American Geophysical Union, and shall be the representative of the Union in its relations with the National Research Council and with the International Geodetic and Geophysical Union. The Executive Committee, in consultation with the Sections, shall nominate to the Executive Board of the National Research Council delegates, or representatives, to the meetings of the International Geodetic and Geophysical Union and of its Sections, in accordance with the regulations fixed by the International Research Council for the voting power of the United States of America.

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ARTICLE 7

Annual Meetings

The American Geophysical Union and its Sections shall meet annually at such time and place as may be chosen by the Executive Committee of the Union. The officers of the Union and of the Sections shall be elected at this annual meeting.

ARTICLE 8

Special Meetings

Special Meetings of the American Geophysical Union, or of its Sections, may be called when necessary by the respective chairmen.

ARTICLE 9

By-Laws

The American Geophysical Union is authorized to enact such by-laws as may be necessary for the performance of its functions and duties.

ARTICLE 10

Amendments

Amendments to the Statutes of the American Geophysical Union shall be subject to the approval of the National Research Council.

BY-LAWS

The fiscal year of the American Geophysical Union shall conform to the fiscal year of the National Research Council.

Standing committees on Statutes and By-Laws, on Membership, on Meetings, and on Budget, shall be appointed for the ensuing fiscal year by the Chairman-elect of the Union prior to the beginning of each year.

All committees of the American Geophysical Union shall terminate at the end of the fiscal year for which they may be appointed.

Meetings of the Union shall be called at least thirty days in advance, and those present at the meeting shall constitute a quorum.

Meetings of the Executive Committee shall be called by the Chairman, and those present shall constitute a quorum.

Final action shall not be taken by the Executive Committee on matters affecting any Section in the absence of the Chairman of such Section, or his representative.

No mail ballot shall be closed until at least thirty days after the date of issue.

After thirty days' notice has been given, amendments to the Statutes (all of which are subject to the approval of the National Research Council) may be voted on either by mail or at a regular meeting of the Union.

Amendments to the By-Laws may be proposed either by mail or at a regular meeting; when voted on by mail they require for adoption a majority vote of

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the members; when voted on at a regular meeting they require for adoption a three-fourths vote of the members present.

Any amendment to the Statutes or By-Laws proposed by at least five members shall be submitted for vote to the members of the Union by the Executive Committee.

A member of the American Geophysical Union may be dropped from the Union by a three-fourths vote of the members of the Executive Committee.

Statutes and By-Laws adopted by a Section shall not conflict with the provisions of the Statutes and By-Laws of the Union.

Matters pertaining to a Section or Sections, and not pertaining to the Union as a whole, shall be acted upon by the Section or Sections concerned.

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[1]Total number of members on July 1, 1926, is 71. The letters following each name indicate the sections with which the member is affiliated, these being (*a*) Geodesy, (*b*) Seismology, (*c*) Meteorology, (*d*) Terrestrial Magnetism and Electricity, (*e*) Oceanography, and (*f*) Volcanology.

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Johns Hopkins University
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Seismology	L. H. Adams (1926-1929)	N. H. Heck (1926-1929)	D. L. Hazard (1925-1928)
Meteorology	H. H. Kimball (1926-1929)	G. W. Littlehales (1926-1929)	A. J. Henry (1926-1929)
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Oceanography	T. W. Vaughan (1926-1929)	G. T. Rude (1926-1929)	Austin H. Clark (1926-1929)
Volcanology	T. A. Jaggar, Jr. (1926-1929)	F. E. Wright (1926-1929)	R. B. Sosman (1925-1928)

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A. J. Henry, Secretary (1926-1929)
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H. H. Kimball, Chairman (1926-1929)
G. W. Littlehales, Vice-Chairman (1926-1929)
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W. E. Parker
G. T. Rude
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J. B. Macelwane
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S. J. Mauchly
R. A. Millikan
W. E. Parker
W. J. Peters
W. F. G. Swann

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N. L. Bowen
William Bowie
L. J. Briggs
E. W. Brown
F. W. Clarke
Whitman Cross
R. A. Daly
A. L. Day
W. J. Humphreys
T. A. Jaggar, Jr., Chairman (1926-1929)
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S. J. Mauchly
F. A. Perret
H. F. Reid
R. B. Sosman, Secretary (1925-1928)
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Louis A. Bauer, 1922-24	Arthur L. Day, 1922-24	W. J. Humphreys, 1921-22
H. F. Reid, 1924-26	*H. S. Washington*, 1924-26	William Bowie, 1922-25
H. S. Washington, 1926-29	G. W. Littlehales, 1926-29	*J. A. Fleming*, 1925-28

OFFICERS OF THE SECTIONS[1]

SECTION	CHAIRMAN	VICE-CHAIRMAN	SECRETARY
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	J. F. Hayford, 1922-24	R. L. Faris, 1922-24	William Bowie, 1922-25
	R. L. Faris, 1924-26	J. F. Hayford, 1924-25	*W. D. Lambert*, 1925-28
	William Bowie, 1926-29	*William Bowie*, 1925-26	
		F. E. Wright, 1926-29	
(*b*) Seismology	H. F. Reid, 1920-22	J. C. Branner, 1920-22	H. O. Wood, 1920-22
	W. J. Humphreys, 1922-24	J. B. Woodworth, 1922-24	*D. L. Hazard*, 1922-28
	J. B. Woodworth, 1924-26	*L. H. Adams*, 1924-26	
	L. H. Adams, 1926-29	N. H. Heck, 1926-29	
(*c*) Meteorology	C. F. Marvin, 1920-22	W. J. Humphreys, 1920-22	*A. J. Henry*, 1920-29
	E. H. Bowie, 1922-24	R. DeC. Ward, 1922-24	
	C. G. Abbot, 1924-26	*H. H. Kimball*, 1924-26	
	H. H. Kimball, 1926-29	G. W. Littlehales, 1926-29	
(*d*) Terrestrial Magnetism and Electricity	Louis A. Bauer, 1920-22	W. F. G. Swann, 1920-22	*J. A. Fleming*, 1920-29
	W. F. G. Swann, 1922-24	Louis A. Bauer, 1922-24	
	Louis A. Bauer, 1924-26	*N. H. Heck*, 1924-26	
	N. H. Heck, 1926-29	J. H. Dellinger, 1926-29	
(*e*) Oceanography	G. W. Littlehales, 1920-22	A. G. Mayor, 1920-22	J. T. Watkins, 1920
	J. P. Ault, 1922-24	G. W. Littlehales, 1922-24	W. E. Parker, 1920-23
	N. H. Heck, 1924-26	*W. J. Peters*, 1924-26	*G. T. Rude*, 1923-26
	T. W. Vaughan, 1926-29	*G. T. Rude*, 1926-29	A. H. Clark, 1926-29
(*f*) Volcanology	H. S. Washington, 1920-22	R. A. Daly, 1920-22	H. O. Wood, 1920-21
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	T. A. Jaggar, Jr., 1924-29	*N. L. Bowen*, 1924-26	
		F. E. Wright, 1926-29	
(*g*) Geophysical Chemistry[2]	Arthur L. Day, 1920-22	F. W. Clarke, 1920-22	R. B. Sosman, 1920-24
	H. S. Washington, 1922-24	Whitman Cross, 1922-24	

DATES OF ANNUAL MEETINGS OF UNION AND OF ITS SECTIONS

First, April 23, 1920
Second, April 18-20, 1921
Third, March 6, 8, 1922
Fourth, April 17-19, 1923
Fifth, May 1-3, 1924
Sixth, April 30, May 1, 1925
Seventh, April 29, 30, 1926

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[1] The names of the officers for the seventh annual meeting are indicated by italics.
[2] Discontinued May 31, 1924, as International Union failed to provide for such a Section.

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RESOLUTIONS

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RESOLUTION ON THE VARIATION OF LATITUDE

(Submitted by Section of Geodesy)

Whereas, The problem of the variation of latitude concerns not only astronomy, but also geophysics in its broadest sense, as is evidenced by the appointment by the International Astronomical Union and the International Geodetic and Geophysical Union of a joint committee consisting of astronomers, geodesists, and geophysicists to confer with and advise the officers of the organizations conducting the present latitude-variation stations on an international cooperative plan, and

Whereas, The accepted method of studying this problem is by the operation of a chain of latitude stations on the same parallel, all using a common program of observations, and

Whereas, The great extent of the United States in longitude suggests that its contribution to this important piece of international work should include more than the maintenance of the present single station at Ukiah, California, and

Whereas, The original number of latitude-variation stations on the thirty-ninth parallel of latitude has been reduced from six (three of which were in the United States) to three, a number found to be too small for the adequate study of the many elements that are now known to enter into this problem, and

Whereas, Of the abandoned latitude stations that at Gaithersburg, Maryland, would be the easiest to re-establish and the most useful, and

Whereas, The importance of reoccupying this station is recognized by experts and has been urged many times in the unanimous reports of committees of the American Section of the International Astronomical Union, duly adopted by the Section, and

Whereas, The International Astronomical Union, meeting at Cambridge, England, in 1925, has urged the Director of the United States Coast and Geodetic Survey to endeavor to secure the reoccupation of Gaithersburg, therefore be it

Resolved, That the American Geophysical Union strongly recommends that observations be resumed at the Gaithersburg latitude station, preferably under the direction of the United States Coast and Geodetic Survey, which now supervises the work at the latitude station at Ukiah, California, and be it further

Resolved, That copies of this resolution be sent to the President of the United States, to the Secretary of Commerce, to the Director of the United States Coast and Geodetic Survey, to the President of the National Academy of Sciences, to the President of the American As-

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tronomical Society, to the President of the Geological Society of America, and to the President of the Seismological Society of America.

RESOLUTION CONCERNING THE TOPOGRAPHIC MAPPING OF THE UNITED STATES

(Submitted by Section of Geodesy)

Whereas, Accurate knowledge of the geographic positions, elevations, and configuration of the ground is essential to the efficient carrying on of geophysical investigations, and

Whereas, The results of these investigations have great scientific and practical value, therefore be it

Resolved, That the American Geophysical Union heartily endorses the plan of the United States Government to complete the topographic mapping of this country in the near future, and be it further

Resolved, That copies of this resolution be sent to the President of the United States, the President of the Senate, and the Speaker of the House of Representatives.

RESOLUTION ON GREATER UNIFORMITY IN PYRHELIOMETRIC MEASUREMENTS

(Submitted by Section of Meteorology)

Whereas, In the interest of convenience to investigators, greater uniformity in pyrheliometric measurements is desirable, therefore be it

Resolved, That the Meteorological Section (*c*) of the International Union of Geodesy and Geophysics be requested (1) to authorize its Commission on Solar Radiation to encourage in every way possible the maintenance of an international network of pyrheliometric stations for obtaining directly comparable measurements of the intensity of solar energy, (2) to include as many high-level stations as practicable in this network, and (3) to provide that, especially at high-level stations, attention be given to the measurement of the ultra-violet radiation and the ozone content of the atmosphere, and

Resolved, That the above-named Commission be authorized to cooperate with the Commission on Solar Radiation of the International Meteorological Committee in arranging for the intercomparison of substandard pyrheliometers for use in different countries, in preparing a program to be recommended for daily observations, and in securing prompt publication of monthly summaries of results, and

Rseolved, further, That a copy of these resolutions be sent to the General Secretary of the International Geodetic and Geophysical Union

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(Colonel H. G. Lyons), and to the Chairman of the Committee of the International Research Council for the Study of Solar and Terrestrial Relationships (Dr. S. Chapman, Imperial College of Science, London, England).

RESOLUTION ON SOLAR-RADIATION STATIONS AND RESULTS

(Submitted by Section of Meteorology)

Whereas, In view of the probable early completion of arrangements in southwest Africa for determining the constant of solar radiation, and the availability thereafter of such data from three stations, one each in North America, South America, and southwest Africa, and

Whereas, It is claimed that the provisional values of these determinations are an aid in weather forecasting, therefore be it

Resolved, That the American Geophysical Union expresses its great pleasure and satisfaction in the purpose of the Smithsonian Institution and the National Geographic Society to maintain the stations abovementioned for a period of at least four years, and be it further

Resolved, That the Astrophysical Observatory of the Smithsonian Institution be, and hereby is, requested to make the data of these stations available at the earliest practicable moment to all organized weather services, and

Resolved further, That a copy of these resolutions be sent to the Secretary of the International Meteorological Committee (Th. Hesselberg, Oslo, Norway), for transmission to the various governmental weather services adhering to that Committee, with a request for cooperation in the attempt to correlate data of solar radiation with terrestrial weather, and a copy also to the General Secretary of the International Geodetic and Geophysical Union (Col. H. G. Lyons).

RESOLUTION ON GRAVITY AT SEA[1]

(Endorsed by sections of Geodesy and Seismology for favorable consideration)

Whereas, A method for the determination of gravity at sea with an accuracy comparable to that obtainable on land has been perfected by Dr. F. A. Vening Meinesz of the Dutch Geodetic Commission and has been successfully used by him on two voyages on a submarine, one from Holland to Java by way of the Suez Canal, and the other from Holland

[1]Adopted by Division of Geology and Geography at its annual meeting of April 24, 1926, and approved by Division of Foreign Relations of National Research Council on April 25, 1926.

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to the Suez Canal, and the method will again be used by Dr. Meinesz during the present summer on a voyage from Holland to Java by way of the Panama Canal, and

Whereas, The deficiency in gravity observations over the ocean areas and inland seas is retarding geological and geophysical studies, and

Whereas, The desirability of making gravity observations at sea has been recognized by the Section of Geodesy of the International Geodetic and Geophysical Union which, by suitable resolutions, has urged all nations having navies to make observations similar to those made by Dr. Meinesz, therefore be it

Resolved, That the Division of Geology and Geography of the National Research Council of the United States commends in the highest terms the Dutch Geodetic Commission and the Dutch Navy for making it possible for Dr. Meinesz to carry on his gravity observations at sea and expresses the hope that every maritime nation may find it possible to supplement the magnificent work of Dr. Meinesz by making additional gravity determinations at sea, especially near its own coasts. We especially commend this work to the Navy Department and to the Coast and Geodetic Survey of the United States of America, and

Be it further Resolved, That a copy of this resolution be sent to the President of the United States, to the Secretary of State, to Dr. F. A. Vening Meinesz, to Dr. J. J. Mueller, President of the Dutch Geodetic Commission, to the Admiral of the Dutch Navy, to the Secretary of the United States Navy, to the Secretary of Commerce, and to the Director of the United States Coast and Geodetic Survey.

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REPORTS AND PAPERS

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GENERAL MEETING

(Washington, D. C., April 30, 1926)

SYMPOSIUM ON THE CONSTITUTION OF THE EARTH

THE DENSITY OF THE EARTH AND THE INFERENCES TO BE DRAWN FROM IT

P. R. Heyl

The first recorded estimate of the density of the Earth was made by Newton. It is to be described rather as a guess than as an estimate, as may be seen by reading Newton's original words (Principia, Book III, Prop. X, Theorem X):

"But that our globe of Earth is of greater density than it would be if the whole consisted of water only, I thus make out. If the whole consisted of water only, whatever was of less density than water, because of its less specific gravity, would emerge and float above. And upon this account, if a globe of terrestrial matter, covered on all sides with water, was less dense than water, it would emerge somewhere; and the subsiding water falling back, would be gathered to the opposite side. And such is the condition of our Earth, which in a great measure is covered with seas. The Earth, if it was not for its greater density, would emerge from the seas, and, according to its degree of levity, would be raised more or less above their surface, the water of the seas flowing backwards to the opposite side. By the same argument, the spots of the Sun, which float upon the lucid matter thereof, are lighter than that matter. And however the planets have been formed, while they were yet in fluid masses, all the heavier matter subsided to the center. Since, therefore, the common matter of our Earth on the surface thereof is about twice as heavy as water, and a little lower, in mines, is found about three or four, or even five times more heavy, it is probable that the quantity of the whole matter of the Earth may be five or six times greater than if it consisted all of water; especially since I have before showed that the Earth is about four times more dense than Jupiter."

Since Newton's day, a number of different experimental methods have been employed in the attempt to determine the density of the Earth. By far the best method is that of the torsion balance, first used by Cavendish in 1798. He obtained for the density of the Earth the value 5.45.

Other experimenters during the nineteenth century obtained rather widely differing values by this method. The accepted figure at present is that obtained independently by Boys in England and Karl Braun in Bohemia about 1896. Their values happen to agree to three decimal

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places, 5.527, but the separate observations vary in the second place of decimals. Consequently, Poynting in his excellent article on "Gravitation" in the Encyclopedia Britannica considers the value to be 5.53.

A value of 5.53 was obtained about the same time by Eötvös, but he did not consider his work at all accurate. It was undertaken as a side-issue, to test the sensitivity of a torsion balance which Eötvös had constructed for other purposes. His attracting masses were built up of blocks of lead, and no accurate allowance could be made for the interstices.

Dr. G. K. Burgess, the present Director of the Bureau of Standards, obtained in 1901 the figure 5.55. This work was undertaken with a time limit upon the experimenter, being thesis work for a degree at the Sorbonne. Dr. Burgess always retained his interest in the question, and felt that he would like to repeat the work under more favorable conditions. When he became Director of the Bureau of Standards in 1923 he saw his opportunity, for it is only with the facilities of such an institution to draw upon that it may be hoped to improve upon the excellent work of Boys and Braun.

The redetermination of this important constant at the Bureau of Standards is still in progress. The program of observations will probably be concluded in December of the present year, but the computations are very heavy and will take some time longer. The work has advanced to a stage where it is indicated that the first three figures (5.53) of Boys and Braun will be verified, and a fourth figure obtained in addition.

Since the average density of the crust of the Earth is between 2 and 3, it follows that the center of the Earth must, as Newton suspected, be composed of much heavier materials. Other lines of evidence, to be described by the speakers following, indicate the probability that the center of the Earth is a large ball of iron.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

SEISMIC WAVES, AND WHAT WE LEARN FROM THEM AS TO THE INTERIOR OF THE EARTH

ROBERT B. SOSMAN

Mr. Adams has asked me to present this subject, not because I have made any important new contributions to it, but because I recently compressed what we know of the interior of the Earth into ten one-hour lectures, which material was then further abstracted into a one-hour lecture at another institution. It is only one additional step in high-pres-

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sure technique, with which Mr. Adams is so familiar, to compress the one-hour lecture into ten minutes.

The title says "seismic waves." I would broaden it to "elastic waves," for the earthquakes are not essential to this branch of the science of the Earth's interior structure, a science that I have ventured to call *geotaxology*. Earthquakes are only a convenient means, though not a very satisfactory one, for supplying elastic waves. Future progress in the science will undoubtedly see an increasing use of artificial and therefore controllable waves, such as may be produced by an explosion or by the fall of a heavy body.

If the Earth were a homogeneous and isotropic body, a mechanical impulse at a point in its interior would send out two spherical waves, rapidly becoming distinct and independent. One is the compressional, longitudinal, or sound wave, whose speed V_c is given by $V^2_c = (K + 4/3\ R)/D$, where K is the incompressibility, R is the rigidity, and D is the density The other is the distortional or transverse wave, whose speed is given by $V^2_d = R/D$. At the free surface the impulse produces a complex set of resultant waves, of which the well-known Rayleigh wave is a special case. In a radially heterogeneous Earth these various types of interior and surface waves still persist, though modified in character.

To obtain information concerning those parts of the Earth through which the elastic waves have traveled, it is necessary to make quantitative measurements on them. The measurable quantities fall naturally into two groups, namely: (*A*) Quantities peculiar to the waves themselves, such as wave-speed, group-speed, period, amplitude, and extinction; (*B*) quantities relating the waves to the Earth, such as speed of surface appearance, angles of emergence (true and apparent), and direction of vibration.

For a given type of waves, such as the compressional, these quantities can be measured singly, and they can also be combined in various ways. Furthermore, taking a given quantity or combination, comparisons can be made between compressional and distortional types. Altogether there results a large variety of possible kinds of quantitative information.

Among the principal deductions already made from quantitative measurements of this kind are the following results relative to the Earth's interior:

(1) The Earth is essentially a solid object. Compressional waves can be transmitted by a liquid or a gas, but the transmission of distortional waves implies rigidness, at least to forces of short period. If there is any liquid material in the outer mantle, it must be confined to

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small pockets or thin layers. It is not yet certain that distortional waves are transmitted by the core, but if they are, as now seems probable, then the entire Earth is proved rigid.

(2) Poisson's ratio for the material of the interior is not far from the value 1/4, being a little above rather than below this. The range of actual values obtained from the speeds of the two waves is 0.25 to 0.28.

(3) The Earth is probably spherically homogeneous below a depth of perhaps 200 kilometers; that is, its properties at any point on an imaginary interior surface of constant radius are the same as at any other point on that surface. This follows from our experience that the average time-curve becomes more precise as more data are obtained from different parts of the Earth. As unexplained minor discrepancies still persist, however, it will be best to say only that there is as yet no definite evidence *against* spherical homogeneity and nothing in the elastic-wave data which would support any hypothesis of deep-penetrating spherical inhomogeneities or wedges.

(4) The Earth has a core whose properties are distinctly different from those of the rest of the Earth. The radius of the core is about 3,500 kilometers and the depth to its surface accordingly about 2,900 kilometers.

(5) The core reflects and refracts the elastic waves as if it had a clearly marked surface, at which there is a considerable change in density and elastic constants. The data are not in agreement with any hypothesis which calls for a gradual change in composition or properties from core to mantle, taking place through a zone which is a considerable fraction of the radius.

(6) The speed of compressional waves is considerably less within the core than in the material outside.[1] Without further information than is yielded by the elastic waves, it is not possible to say whether this is due to increased density or to decreased incompressibility (K) and decreased rigidity (R).

Other less certain facts yielded by the measurement of the properties of elastic waves are the discontinuities at depths of 1,200, 1,700, and 2,450 kilometers below the surface. Discontinuities near the surface, namely, at 60 and 70 kilometers, are considered in the next paper.

Geophysical Laboratory,
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Washington, D. C.

[1] This was illustrated experimentally by an optical analogy, by means of the shadow cast by a solid sphere of glass in air.

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THE EARTH'S CRUST AND THE DISCONTINUITY BENEATH IT

L. H. Adams

The Earth is now believed to have a real crust—not in the old sense of a solid layer floating on a liquid interior, but rather in the sense of a thin covering of material radically different in composition from the sphere which it surrounds. It is interesting to recall that only a few decades ago Osmond Fisher argued with convincing and almost flawless logic that the solid crust of the Earth rested on a mobile liquid. But it is now universally admitted that the whole Earth (except possibly near the center), far from having the mobility commonly associated with the word liquid, has a rigidity approaching or exceeding that of steel.

Let us now note the various lines of geophysical evidence which show that the region 50 or 100 kilometers below the surface possesses certain peculiarities.

In the first place, the results of gravity measurements have established the reality of isostatic adjustment. The thickness of the layer in which gravitative stresses are not completely relieved by yielding of the rocks is usually placed at 60 to 100 kilometers. Evidently there is an outer layer which differs in some way from the material below it. In this connection, it is important to observe that the conclusions reached by measurements of gravity have recently been strikingly confirmed by calculations based on the known densities of rocks collected at the surface in various parts of the Earth.

The temperature increases steadily with increasing depth. Now, it is just in this region, 60 to 100 kilometers below the surface, that the temperature approaches closely to the melting point of silicate mixtures corresponding to the ordinary rocks. The fact that at this depth the rocks are so near their melting point would indicate an increased ability to flow, and might have an important bearing on the phenomenon of isostasy.

Perhaps the most direct and definite evidence concerning the crust of the Earth comes from the results of seismic observations. These results, and in particular those for near earthquakes, show us a discontinuity at a depth of about 60 kilometers. At this depth the velocity of the longitudinal vibrations increases rather suddenly from 5.8 to 8.0 km./sec. and on account of the change in elasticity the earthquake waves undergo a marked reflection.

Finally, laboratory measurements on the elastic constants of various rocks have contributed to our knowledge concerning the composition of the Earth's crust and of the material below the crust. By comparing the wave-velocities at various depths with the velocities calculated from

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the measured elastic constants of typical rocks, we are able to determine the composition of the material at any given depth. In this way it has been learned that the crust is a shell, almost entirely of granite, resting on material which is uniform and of the composition of peridotite all the way down to the central iron core.

It may be said that the seismic results prove too much. If we accept these results at their full face value, basaltic rocks are removed from the picture. That basalt should occur only in insignificant amounts within the Earth is an idea which will be vigorously opposed by most geologists. Possibly the seismic results are neither sufficiently accurate nor properly interpreted, and further investigation in this field is of the very highest importance.

The various considerations mentioned above—geodetic, thermal, seismic, and elastic—all point to change or discontinuity of some kind at a depth which is less than 100 and more than 50 kilometers. Whether or not the singularities revealed by the different methods pertain to one and the same level is as yet an unsolved problem. All of the data, however, are in accord with the idea of an originally molten Earth, the silicate part of which solidified (crystallized) from the bottom upward, leaving the present crust as a residuum of impurities concentrated by an orderly differentiation of the Earth as a whole.

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THE CHEMICAL COMPOSITION OF THE EARTH, OF METEORITES, AND OF THE SUN'S ATMOSPHERE

H. S. WASHINGTON

The preceding speakers have pointed out several of the lines along which we arrive at a knowledge of the constitution of the Earth. In these, and several other, ways we have come to believe, and with a high degree of probability of our belief, that a core of metallic iron, or nickel-iron, occupies the center of the Earth. This metallic core has a radius of about 3,400 kilometers. It changes, by the gradually increasing assumption of silicate material, first into a "lithosporic" shell—one in which silicates (especially olivine and pyroxene) are included sporadically in the metal, and then into a "ferrosporic" shell, in which gradually decreasing amounts of metal occur sporadically in silicate rock. This mixed zone is about 1,400 kilometers thick, and, for purposes of computation, we may assume that the lithosporic and the ferrosporic shells are each 700 kilometers thick. Outside of this is a shell of peridotite—a rock made up of olivine and pyroxene—which is about 1,540 kilometers thick, and above this the "crust" of the Earth, about 60 kilometers thick, the

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lower two-thirds being basaltic and the upper one-third being granitic.

The respective volumes and masses of these various shells and of the central metallic core have been calculated. Also, on the assumption that the chemical and mineral composition of the core and of the lithosporic, ferrosporic, and peridotitic shells is that of the average of the corresponding meteorites, and with a fairly safe knowledge of the average composition of the basalts and the general granitic rocks of the "crust," from these data the general chemical composition of the whole Earth has been calculated. The result is given in Table 1.

Table 1. *Chemical Composition of the Earth*

Iron (metal)	31.82	Sulphur	0.64
Nickel (metal)	3.16	Sodium	0.39
Cobalt (metal)	0.23	Chromium	0.20
Oxygen	27.71	Potassium	0.14
Silicon	14.53	Phosphorus	0.11
Magnesium	8.69	Manganese	0.07
Iron (silicate)	7.94	Carbon	0.04
Calcium	2.52	Titanium	0.02
Aluminum	1.79		100.00

These results are admittedly approximate; but, if the assumptions are reasonably correct, they cannot be very far wrong, except that the percentages for sulphur, phosphorus, and carbon are probably too low. It appears that four elements, iron, by far the most abundant, oxygen, silicon, and magnesium, make up 90.7 per cent of the Earth. These, with three others, nickel, calcium, and aluminum, make up 98.2 per cent; and with five others, sulphur, sodium, cobalt, chromium, and potassium, each in amount of less than one per cent, constitute 99.8 per cent of the Earth. Probably phosphorus, to the extent of 0.1 per cent, and carbon and chlorine, to the extent of about 0.05 for both, should be added to the list. It thus appears that the Earth, as a whole, is composed almost exclusively of but 12 or 14 elements, and that the percentage of the 80 or 78 others is almost negligible, as they, altogether, do not constitute very probably more than about 0.1 per cent of the Earth.

These most abundant elements are all of low, but not the lowest, atomic weight and atomic number; the highest atomic weight represented is 59 (cobalt), and the highest atomic number is that of nickel (28). Without going into details, it may be said that there is a serial progression, from the center to the surface, as regards most of these elements, the progression being positive for some and negative for others.

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A feature of special interest, bearing on our views as to the derivation of the Earth and the other planets from an original nebula or a primeval, disrupted sun, is the correspondence between the composition of the whole Earth and that of the sun's atmosphere. By spectroscopic methods one may arrive at a roughly approximate idea of the relative abundance of the elements that constitute the atmosphere of the sun. On comparison, it is found that, of the eleven most abundant elements in the Earth, nine (Fe, Si, Mg, Ni, Ca, Al, Na, Co, Cr) are among the eleven most abundant in the sun's atmosphere. Some slight discrepancies are explicable by the differences in physical conditions and by the peculiarities of the spectroscopic observation of certain elements—oxygen, for example.

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THE ORIGIN OF THE OCEAN AND THE ATMOSPHERE

W. J. Humphreys

How the Earth acquired an atmosphere and where the oceans came from, have been fascinating problems ever since there were children to ask questions and grown-ups who couldn't answer them. However, experiments of the physicist and observations of the geologist and the astronomer have furnished the warp and the woof with which the mathematician at last has woven a theory that clothes both these Sphinxes in rare and beautiful raiment.

To begin, not truly at the beginning, but as far back as even part-knowledge permits, we believe that all that we call electricity and all that we call matter consist of two things as yet unresolved—the electron and the proton, the negative and the positive electric atoms, or at most, these ultimate charges and their carriers. At any rate, these are the most elementary entities of which there is any fairly definite evidence. We have no knowledge of the origin of either the electron or the proton. They can exist separately, from which we infer that they may have originated differently and in different amounts, the excess diffusing itself to infinite rarity. On the other hand, the equality of their charges suggests a common and simultaneous origin. But, be that as it may, they usually are combined in various equal numbers, thereby forming all the material elements from hydrogen to uranium. Hence, wherever matter occurs in great quantity, as in a star or a planet, one may expect to find all the possible elements in varying proportions, and also such compounds of them as the temperature and other conditions favor. Presumably, therefore, every heavenly object, however nebulous or condensed, has within itself, as certainly as our own sun has, the makings of an atmosphere and an ocean. Evidently, then, when the Earth was pulled out of the

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sun by the tidal action of a passing star of much greater mass, there were taken along the hydrogen, oxygen, and nitrogen of the ocean and the air as well as the iron, silicon, aluminum, and other elements of the lithosphere.

The portion of the sun thus torn out by tidal action broke off during this process, if we accept Jeffrey's logic,[1] in separate masses which, owing to expansional and radiational cooling, soon in great measure became liquid. The rest was gases and vapors surrounding these centers, and cosmical dust and debris left throughout the disk of the new-born solar system. In the case of the Earth, it appears that the gravity pull of the liquid globe was quite sufficient to retain water vapor, if such existed, and all the gases of the atmosphere except hydrogen and helium.

After a relatively very short period, only a few thousand years, a more or less stable crust formed, consisting essentially of rock-material, the iron and other heavy elements through the action of gravity having formed the inner core. The surface temperature then rapidly fell to a value comparable to that which seems to have obtained ever since, leading to condensation of most of the water vapor, if it existed in large quantity, and to a well-nigh perfect conservation of all atmospheric gases, including now even hydrogen and helium. But whatever this primordial supply of free air and free water vapor, the crusting of the Earth was accompanied and followed by lava flows and other forms of eruptions all giving off then, as they do now, vast volumes of steam, carbon dioxide, nitrogen, hydrogen, oxygen, and other gases, each of which had been absorbed, occluded, combined, or otherwise taken up by the rocky materials while in their previous gaseous or liquid state. In this way such original gases and initial water as may have existed were rapidly supplemented until an atmosphere substantially as it exists today had accumulated, and great oceans had covered most of the Earth.

Later on, when vegetation had developed chlorophyl-bearing types, the oxygen of the air presumably was greatly increased by their absorption of carbon dioxide and liberation of free oxygen.

Such, in broad and general terms, is the latest theory of the origin of our atmosphere and our oceans, a theory of beautiful texture woven by Mathesis from the many-colored threads of observation and experiment.

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DISCUSSION FOLLOWING SYMPOSIUM

Dr. Bowie. I think that we should go back one step further in trying to account for the presence of oceans. The greatest contribution, in my

[1] Jeffrey's *The Earth*. Cambridge University Press. 1924.

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judgment, to the knowledge of why we have oceans was made by Dr. Henry S. Washington when he correlated the analyses of igneous rocks with the elevation of the ground. According to this correlation, there is a very definite relation between the norms derived from the quantitative and qualitative analyses and the general elevation of the Earth's surface surrounding the places where the rocks were found. The larger norms apply to the lower elevations. It seems to me that we have here a clew as to why we have an irregular surface of the Earth with wide basins, which we call oceans, and broad plateaus or highlands called continents. Of course, to explain the ocean with entire satisfaction, we should go back even one step further and try to learn why the heavier elements are present in larger percentages in some portions of the crust than they are in others. I think I am correct in saying that Dr. Washington is planning to attack this problem in the not distant future. In any event, we had an irregular surface of the Earth to start with before the age of rainfall or what is better known as the age of sedimentation.

Dr. Washington. One of the most important outstanding problems in regard to the constitution of the Earth is why there are the great continental masses and the still vaster oceanic basins. The former are composed of compartively light, granitic rocks, while the ocean floors are basaltic, which is in accord with the doctrine of isostasy. But, on the whole, it appears to me that this regional heterogeneity of the crust, complicated by the existence of co-magmatic regions of different chemical composition, is one of the most difficult features that we have to explain in discussing the Earth's constitution.

Dr. Reid. Professor Joly of Trinity College, Dublin, thinks that as the Earth cooled originally it was surrounded by a liquid magma; that the acid rocks separated from this magma and formed the material of the continents, which, being lighter than the remaining basaltic magma, floated in it. When the basaltic layer solidified, its density increased and the continents floated still higher. It must be left to the petrographers to decide if this suggestion of differentiation in the magma will hold.

Dr. Bauer. This question of an iron-core hypothesis of the constitution of the Earth is naturally of great interest to the magnetician. Chamberlin expressed the view that our knowledge of the Earth's interior is to be chiefly gained from seismology and terrestrial magnetism. I may recall that Schuster in his presidential address before the Physical Society of London in 1912 reviewed the various theories with regard to the possible causes of Terrestrial Magnetism. He considered that it would be premature to discard, before further investigation, the hypothesis that an iron core of the Earth may be the cause. As we go into the interior of the Earth the temperature continually increases, and it

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has been calculated that at a depth of about twelve miles we would have a temperature at which magnetization could not exist. However, this calculation neglects any possible effect on the critical temperature of magnetization which may be caused by the increased pressure as we penetrate into the interior. Schuster, accordingly, initiated some experiments to find out whether the loss of magnetism due to increased temperature might be offset by increased pressure. The experiments were difficult. They were carried on at the University of Manchester by Mr. F. Whaley. Some years ago I wrote to Dr. Petavel, who had designed the pressure furnace used by Whaley, as to the continuation of these experiments, possibly at the National Physical Laboratory, but he replied that nothing further had been done. Dr. Adams, of the Geophysical Laboratory, and Mr. Green, of the Department of Terrestrial Magnetism, are now investigating the question as to the effect of pressure on the critical temperature of magnetization. This is one line of inquiry which is of particular interest to us in connection with this symposium. Another line that I may mention is the result of an analysis which I made of the Earth's magnetic field based on actual observations. Let us take the simplest possible case of magnetization of the Earth; namely, the portion of the Earth's magnetic field which is symmetrical about the axis of rotation. The magnetic poles would then coincide with the geographic poles. If the Earth consisted entirely of iron, we might have a uniformly magnetized Earth and the intensity of magnetization for any point on a parallel of latitude could then be represented by the radius of a sphere. In fact, the figure which would represent the intensity of magnetization at all points would be a sphere. If, however, we take the actual observations, as based on the extensive work of the *Galilee* and the *Carnegie* on the oceans and of the various expeditions on land, such a simple representative figure of magnetization is not obtained. Instead, we get a pear-shaped figure, showing some relationship to the distribution of land and water. We thus have evidences of lack of uniformity of magnetization even for the simplest possible case. Furthermore, the pear-shaped figure would have a number of humps in it for different regions of the Earth. It is thus possible that facts derived from a critical study of the Earth's magnetism may assist in obtaining some information with regard to the constitution of the Earth.

Professor Macelwane. I should like to disclaim the responsibility for final pronouncements as to the possibility of transverse waves passing through the core of the Earth. We have observed groups that look like transverse core waves appearing on successive records in an earthquake, but the evidence is not conclusive enough for any definite statement. I think the problem still remains open and that there are two possibilities

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in regard to it. Some calculations we made recently seem to indicate that only a slight fraction of the incident wave energy could enter a rigid core as a transverse vibration and that only a small part of this can emerge in transverse form. Suppose we find eventually that no transverse waves are observed, it may be that the core will not transmit them. But it may also be that they are not absent, but that their energy is too slight to allow them to appear in the midst of other waves.

Dr. Wright. Referring to the question regarding the discontinuities of different layers in the Earth: When light is reflected from a glass surface, there is evidence that light penetrates a certain distance. When the waves from a sonic depth finder strike an oozy bottom, I understand there is a different kind of reflection from that produced by a solid bottom. A number of sound waves may be easily included within the depth of the layer of the ooze. In connection with earthquake waves, the question is, how abrupt is this discontinuity? Is it measured in kilometers or not? How sharp will this reflection be for the transverse waves?

Dr. Adams. This is one of the most important questions in seismology. It should be possible to determine how sharp it is. Possibly the transition zone extends over several tens of kilometers. In general a discontinuity means a zone of transition of the same order of magnitude as one wave length, and if this zone is even a few kilometers in extent it should not be called a discontinuity.

Professor Willis. It has been my privilege to enjoy the discussions on seismology with the physical seismologists and in one or two instances to compare their conclusions with those of the geologist. When my colleagues speak of waves which have been transmitted from a distant focus and seek to find the exact center of that focus, the distance is so great as compared with the area of the origin that they can speak of that area as a point. I have, from the geologist's point of view, an impression that the center is often square miles in extent and that we are dealing sometimes not with a single movement, but with several closely allied movements. A study of the earthquakes in southern California from 1915-1925 has led me to think that some of the heavier earthquakes have each had several centers located on faults some miles apart.

In my work in Chile on the great earthquake of November 10, 1922, I found that the higher intensities were located on many faults, a fact which has been observed in Germany and elsewhere. That may have its bearing upon this question of a zone of discontinuity or a sharp line, since the origin is involved in the study of the path of the wave. I would suggest that the Earth is extremely varied in its phenomena. Judging from what geology teaches, the dynamic histories of different coasts do

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not match each other. Each ocean basin is a dynamic center distinct from any other. I should like to plead for the application of the method of multiple hypotheses, using these valuable results that have come out of the work of some of the men who spoke today, together with geological and other related data.

Dr. Bowie. With regard to the thickness of the crust from the geodetic standpoint, I should say that any value derived from geodetic data is merely a mathematical expression. We have to assume something in our isostatic investigations in regard to the distribution or depth to which heterogeneous densities in the outer portion of the Earth extend. We assume, in these isostatic investigations, a uniform depth of compensation and then proceed to determine what the value of that depth is. Although we can eliminate the gravity and deflection of the vertical anomalies by using a depth of 50 miles almost as completely as by the use of the most probable depth of 60 miles, yet the 60-mile depth is of the order of magnitude of the thickness of the Earth's crust. There is undoubtedly a limit to the depth to which material extends that can maintain its form against gravitational stresses. If this were not true, then the continents would overflow the oceans and the heavier material beneath the oceans would underflow the continents. It is probable that, later on, as data accumulate and investigations are extended, the depth of the crust as computed from seismological data may be brought more closely into harmony with the depth as computed from the geodetic data. There is really not so very much difference between the 60 kilometers of the seismologist and the 96 kilometers of the geodesist.

It should be clearly borne in mind that the geodesist is not eliminating the gravity anomalies. He is attempting to explain them, and by their explanation he hopes to reach some knowledge of geological structure that is not evident from investigations along other lines.

Dr. Reid. Whether this central core transmits transverse vibrations or not, I believe there has been some objection on the score of stability to a liquid center of the Earth.

Prof. Macelwane. The point raised by Professor Willis seems to me to be well answered by the computations made by Dr. Reid some years ago and published in the Bulletin of the Seismological Society of America as to the effect of an extended fault movement in an earthquake on the character of the records of seismographs at greater distances. The conclusion reached was that at any distant place the beginning of a group is determined by waves from that point at which the break occurs first on the fault plane, provided the first movement is sufficiently strong to reach all the stations.

Dr. Washington. With regard to the magnetism of the Earth, one

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point is apparently not appreciated. An argument constantly brought up against the magnetism of the Earth being due to a central core of metallic iron, is that iron loses its magnetism at a temperature of about 785°. This is true of *pure* iron and under atmospheric pressure. But, thus far, we know nothing about the effect of high pressure on the magnetic properties of iron at high temperatures. Also, from analogy with meteorites, we are justified in believing that the central core is of nickel-iron alloy, and we know that the magnetic properties of the nickel-iron alloys differ much from those of pure iron. The addition of less than one per cent of carbon to pure iron will change it, on magnetization, from a temporary to a permanent magnet. Furthermore, there are alloys of such nonmagnetic metals as aluminum, copper, and manganese, that are quite strongly magnetic, and the addition of a quarter of one per cent of manganese to bismuth will make this magnetic. We must, therefore, be cautious in our generalizations from the study of the magnetism of pure iron.

Dr. Reid. The materials of the Earth's crust are of quite different densities in different parts of the Earth's surface; but there are two things, I think, which show the general spherical symmetry of the Earth. The first is the almost perfect conformity of the Earth's surface to an ellipsoid of revolution; the second is the uniformity of the velocity of earthquake waves in different parts of the Earth. The waves from the California earthquake of 1906 arrived at stations equidistant from the origin at closely the same times, independently of the direction or whether their paths were under the ocean or under the continents.

In a recent paper on the characteristics of the interior of the Earth Professor Wiechert is led, through the study of earthquake waves, to the conclusion that the Earth is made up of three layers: A central core of nickel and iron, an outer layer of stony material, and an intermediate layer of a mixture of these two. This corresponds with the conclusions of Williamson and Adams, except that Wiechert's intermediate layer is more uniform. He finds that there is not a great deal of compression, but that the density is largely controlled by the material. He has calculated the radii of these layers to satisfy the astronomical conditions. He also mentions the other layers which Dr. Sosman spoke of, but thinks them rather unimportant.

Dr. Sosman. With regard to the general features of the interior, we may draw a parallel with the experience of the chemists. To the early chemist, silica was an undecomposable substance, ranking with the metals as a chemical *element.* Then it was found to consist of silicon and oxygen, and became a chemical *compound.* Now we know that silicon itself

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is not a single kind of atom but consists of three *isotopes*. Yet it remains true that silica is a chemical substance, and silicon is still a chemical element. So with the Earth's interior, the general features as we now have them are perhaps essentially correct, though subject to minor modifications. In their general form I think they will stand.

Prof. Macelwane. A point not worked out is the question of a possible heterogeneity down under the Pacific. Neumann and Service are obtaining results in this connection which are surprising. Waves traversing layers deep down under the Pacific and coming up at stations like Honolulu seem to differ in their travel times from those which follow equal subcontinental paths by an amount which is beyond the limits of errors of observation. That seems to indicate a problem into which we ought to look much more fully.

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SECTION OF GEODESY

(Washington, D. C., April 29, 1926)

LOWER ST. LAWRENCE RIVER EARTHQUAKE OF 1925 AND COOPERATIVE INVESTIGATION BY THE DOMINION OBSERVATORY AND THE GEODETIC SURVEY OF CANADA

NOEL J. OGILVIE

In 1662 the French settlement along the St. Lawrence River (Fig. 1) was faced with a liquor problem which broke the heart of Bishop Laval, who at that time was head of the Roman Catholic Church in Canada. Excommunication and every means within his power were used to prohibit the sale and use of liquor, but all to no avail, and as a last resource he sailed for old France, hoping to secure assistance from the home government. Hardly had he left the shores of New France when it was believed by many a Mightier Agency had interfered, for, in the year 1663, the St. Lawrence valley was rocked by an earthquake which, if we are to believe history, moved mountains, changed river courses, and, to use the words of the native Indians, "the very trees in the forest danced as though they were intoxicated."

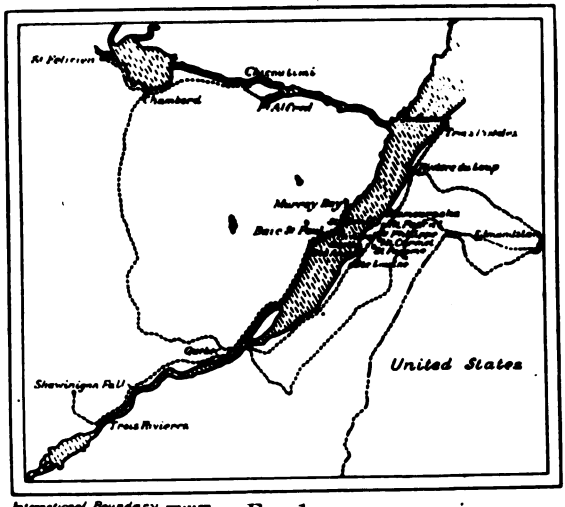

FIG. 1

The earthquake which I wish to refer to particularly today is that which occurred on the evening of February 28, 1925. Coincident with the shock a loud roar was heard in the St. Lawrence valley, while at points as far west as Ottawa there was a noise similar to the passing of a heavy truck upon the pavement; the shock itself lasted only a few seconds, but tremors were felt for the following two weeks. While attending a hockey game in our auditorium at Ottawa, a building which is built of steel, concrete, and brick, I felt the shock. The greatest damage was done in the neighborhood of St. Pacome, Riviere Ouelle,

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Baie St. Paul, and Shawinigan Falls, where occasional stone buildings were cracked or partly wrecked and chimneys tottered over.

The effect upon tombstones was peculiar in that some were lifted vertically several inches and then fell on their sides, while others were left standing but turned in azimuth (Fig. 2); on the north shore the

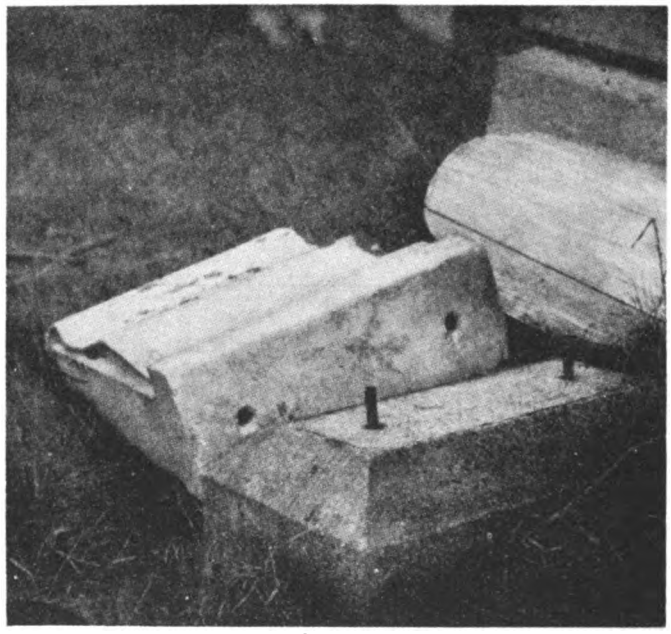

FIG. 2

turning movement in general was clockwise, whereas on the south shore the movement in most cases examined was contra-clockwise.

In a particular case where two marble columns rested on a smooth stone base and were capped by a single smooth stone cap, the position of the base and cap remained unchanged after the quake, but the two columns were turned approximately 45 degrees in azimuth (Fig. 3).

Numerous cracks appeared in the earth's crust between Riviere Ouelle and Riviere du Loup on the south shore, but in no case did they exceed one hundred and fifty feet in length, three inches in width, or twenty feet in depth (Fig. 4); also cracks in the snow mantle were reported from points as far east as Kamouraska. Contrary to paper reports at the time of the quake, it has been found no harm was done to any person physically, except in a few cases where minor cuts were caused by falling glass.

In these days of specialization any one branch of Science is handicapped unless it can have the maximum of cooperation from several other specialists—and in the study under observation, the value of the

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conclusions of a seismologist are limited unless he has cooperation from Geodetic and Geological surveys; that is, he must have reliable horizontal and vertical control by a Geodetic survey and a study of the rock and soil formation from the Geologist. I might say that cooperation has always been the keynote in our relations with the Dominion Observatory and we were very glad to be of service to them in the spring of 1925. We had a system of primary triangulation straddling the St. Lawrence and also a line of precise levels along the south shore—if funds had been available we would both have reoccupied our triangulation stations and relevelled the precise level line, but it was felt that the maximum amount of information consistent with funds at our disposal could be obtained in going over the precise level line. Accordingly, following a request from the Observatory, an engineer and precise leveling party relevelled the 114 miles between Riviere du Loup and Levis. It was believed that any vertical displacement due to the quake would show up in this length of line, since the greatest shock was felt between these two points. In figure number five, the straight line represents the 1915 elevations, and points on the irregular line represent the rise or drop in 1925 from 1915 calculations. Let us examine the 1925 curve; between Riviere du Loup and Riviere Ouelle any change in elevation of bench marks may be accounted for by frost action or instrumental errors; from Riviere Ouelle to Montmagny there is a gradually increasing drop and at the latter place this drop in elevation amounts to 0.37 foot; from Montmagny southwestward there is a gradual pick-up in the difference, and at Levis the closure is shown to be approximately 0.1 foot. Let us examine for a moment the topographical features of the district traversed: At Riviere du Loup we have a rocky plateau with an elevation of 300 feet, at Riviere Ouelle a trough with an elevation of 35 feet, next a fairly level plain 60 miles in length, the average elevation of which is 100 feet, and lastly a plateau behind Levis with solid limestone a few feet below the ground surface and at an elevation of approximately 325 feet above sea level. In passing, I should like to draw your attention to the fact that the Dominion Observatory, in their preliminary survey of the district immediately after the quake, came to the conclusion that the fault line along which the disturbance centered, made its entry to the south shore of the St. Lawrence River at the Riviere Ouelle trough. In figure number six, the bench marks are represented at their actual elevation in 1915, that is the full black line. Heretofore we have considered the 1925 relevelling as it was actually run in the field from Riviere du Loup southwesterly. We are equally at liberty to represent it as run from Levis northeasterly, and if we do this the dotted line here shows the shift in the bench marks in the ten-year interval from 1915 to 1925. Furthermore, we now see the two curves to intersect near St. Pacome, showing

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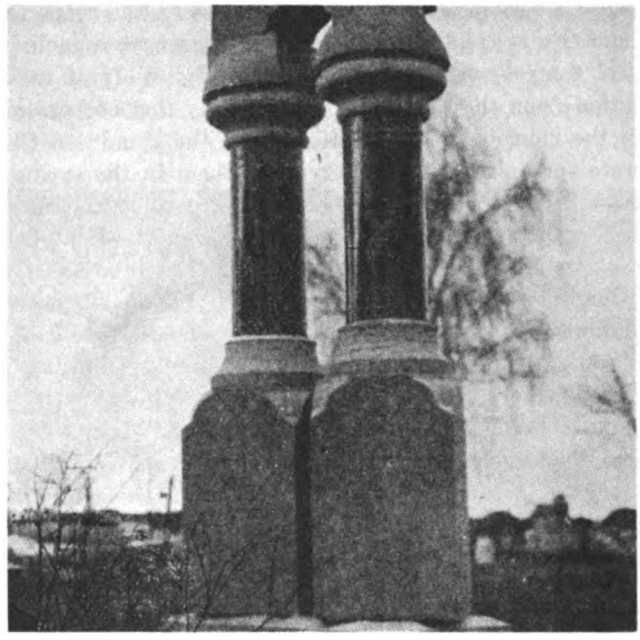

FIG. 3

FIG. 4

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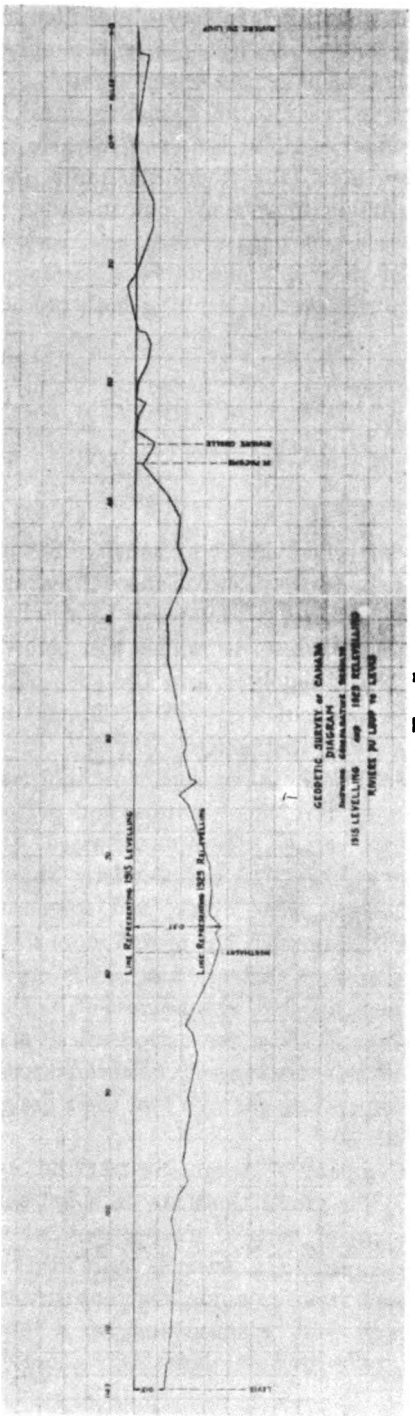
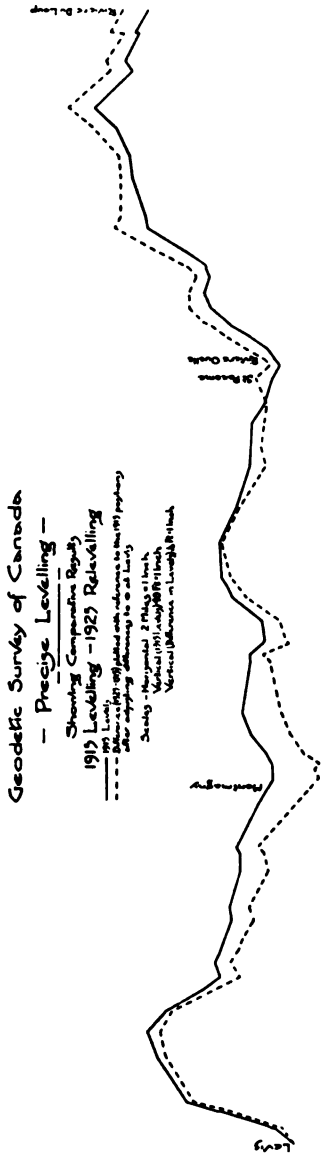


FIG. 5



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a rise in elevation since 1915 for bench marks northeast of St. Pacome and a drop to the southwest. Thus precise levelling has given a complete substantiation of the field observations made by the seismologist.

In conclusion, from the seismograph records, the seismologist calculates the approximate direction and distance of the center of disturbance from the instrument station, the geologist tells where the fault lines exist and where we may expect to find a movement; but in order to definitely determine that there has been a horizontal shift or a vertical displacement and the actual extent of these movements, it is absolutely necessary that Geodetic triangulation and precise levelling both precede and follow an earthquake.

Geodetic Survey of Canada,
Ottawa, Canada

DESIGN OF A PRECISE THEODOLITE

D. L. Parkhurst

The Coast and Geodetic Survey has experienced so much difficulty in the past few years in obtaining satisfactory first-order theodolites, and by this I mean instruments which can be read to one second of arc, that we have decided to design an instrument ourselves which will embody the various desirable features of existing theodolites, and also such other characteristics as our field experience has indicated will aid in making a more rugged, portable, and easily operated instrument.

Briefly, the essentials of a theodolite such as we need are lightness, ruggedness, a perfectly graduated circle, frictionless centers, and perfect optical qualities. Perfection, of course, can only be approximated.

The instrument designed and built by the Coast and Geodetic Survey about 25 years ago has a long telescope, large circle, and spreading microscopes. This theodolite, despite its large size, has proved more satisfactory in many ways than the more modern instruments, but is objectionable because of its bulk and long telescope, and also because of its lack of a vertical circle. This lack prevents its use for astronomical purposes in high latitudes. The axes of this instrument, however, are so frictionless and so little affected by temperature changes that their design has been followed in the new theodolite.

The theodolite built by the Kern Company of Aarau, Switzerland, has a number of very valuable features. The graduations are on a flat surface, not on a cone, permitting the use of vertical microscopes, which reduce the spread. For convenience in reading, a prism is built into the eye-piece so that the circle may be read from an angle, and not directly downward. The telescope is short and well balanced and has a large objective so that plenty of light is admitted—a desirable feature in

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night surveying. It is internal focusing, which renders it practically dust proof and also shortens the length. The alidade center, however,

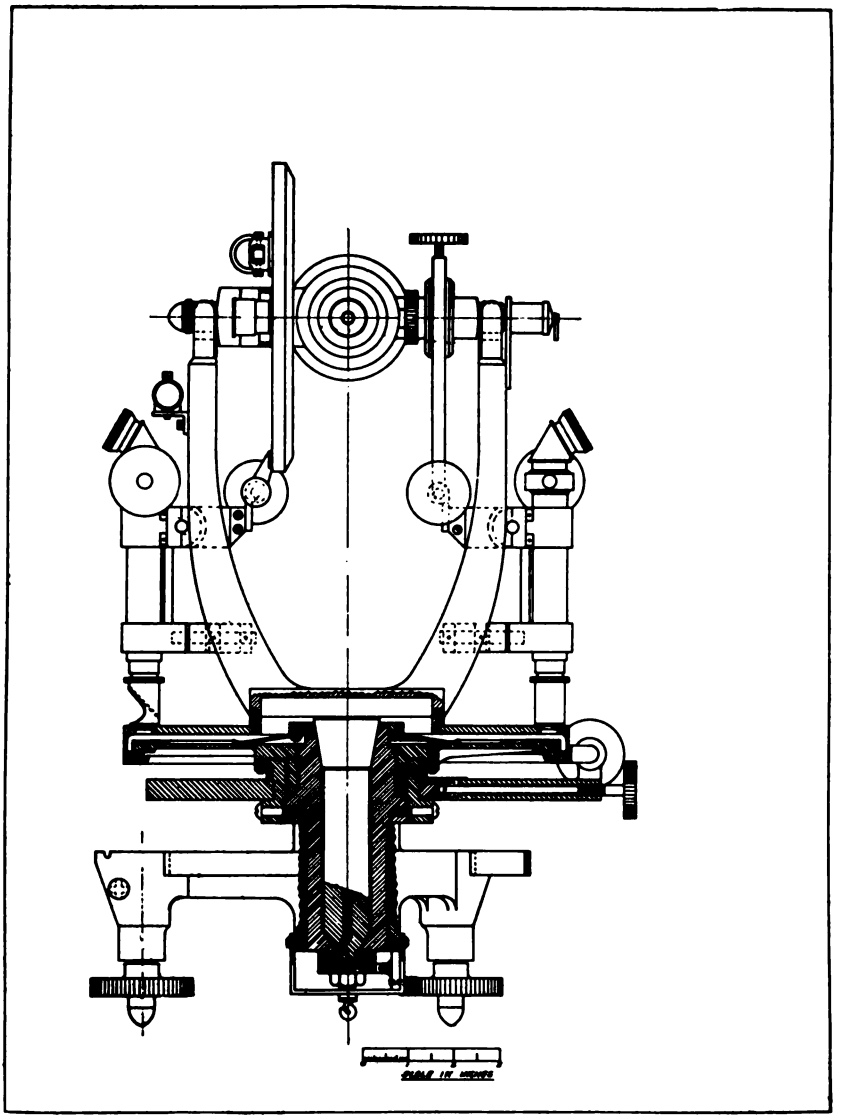

FIG. 1

Cross-section of U. S. Coast and Geodetic Survey 9-inch precision theodolite.

is in the form of a single long taper with a small thrust-bearing at the bottom. We have found it to be considerably affected by temperature changes, with resultant binding. The changes are so noticeable that it

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has been a most unpopular instrument with the observers, as it requires frequent adjustment.

The theodolite made by the Hildebrand Company of Germany, while having a wide spread, has given excellent results, as it is well made, and although it has the single taper vertical axis, yet the temperature coefficient of the axis and its socket are apparently about equal, since little or no temperature effect has been noted. When there is any appreciable difference there is a tendency of the bearing to seize or to be unduly loose, as the case may be. If the socket has a larger coefficient than the axis, a decrease in temperature will cause it to shrink and bind.

Figure 1 shows a cross-section through the new theodolite which we have designed. We have made use of the idea of graduating on a flat surface, with vertical microscopes. These are mounted on a hinged frame so that they may be adjusted radially, but are restrained from circumferential motion by a large ear fitting in a slot in the standard casting. The microscopes will be located 180° apart by mechanical means and the final small adjustment made in the micrometer box itself by moving the comb.

The standards are of L-shaped section in order to obtain the greatest strength with the least weight and are sufficiently high so that the telescope will transit through. The circle is without a clamp, being free to rotate, except for the friction of the spring nut which holds its bearing against the seat. This design eliminates the movement which is occasionally experienced when a clamp is used and tightened. We have used the two-cone-bearing idea on the circle as well as the alidade center to insure freedom from binding due to temperature changes and to furnish a minimum of friction. This type of bearing will wear itself in so that there will be no tendency towards eccentricity because of looseness as the bearing wears. Lugs are provided to take the weight of the circle in case the instrument is inverted.

The alidade center is of steel, and has upper and lower cones of different angles, the bearing surfaces being hardened. The socket is of cast iron, having a temperature coefficient practically the same as that of the steel center so that the effect of temperature changes will be minimized, and the cast iron and steel will form a good anti-friction combination. The outer surface of the socket forms the bearing for the circle so that rotation of both circle and alidade about the same axis is assured.

The alidade axis is pierced with a hole large enough to permit the passage of an insulated wire, through which to bring current for illumination of the cross wires and microscopes. This, you will note, is brought out to an insulated ring. A brush is mounted on a "U"-shaped bridge attached to the tribrach so that the slip ring is exposed and may readily

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be cleaned without in any way disturbing the adjustment of the instrument.

The conductor is brought out through the side of the bearing in order that the mechanical centers, upon which the bearing is constructed, will not be destroyed, as is often the case. When these centers are removed, it is difficult to true up the bearing if it becomes damaged in any way.

The tribrach is of aluminum, with arms hollowed out for lightness, and with a lifting ring cast integral with the arms, the cast-iron bearing socket being tightly threaded in place.

The leveling screws are long and of large diameter, and a cover is placed over the threaded hole in the tribrach to keep out dust and dirt.

This view gives a better idea of how the completed instrument will look. You will note that the standards are slender and rather narrow.

All improvement has been made in the design of the alidade tangent screw in that the motion is imparted by means of a plunger which is restrained from rotation, so that its motion is purely linear. This design eliminates the irregularity of motion and lifting effect which obtains when a rotary point is eccentric or worn obliquely.

The advantages that we believe this new theodolite will possess are: Lightness (it is estimated that the complete instrument will not weigh over 40 pounds); ruggedness; accuracy; easy running centers free from binding due to temperature changes; an instrument which can be used in any latitude; compactness, by virtue of use of vertical microscopes.

U. S. Coast and Geodetic Survey,
Washington, D. C.

RECENT WORK IN GEODETIC TAPE STANDARDIZATION

L. V. JUDSON

The invar base-line tapes used by the U. S. Coast and Geodetic Survey are tested at the Bureau of Standards. Since these tapes are used in the fundamental geodetic surveys of this country, including international boundary lines, it is essential that every precaution be used in the standardization.

It is now possible to measure the change in the distance between the end graduation lines of such a tape when a small weight is placed on the tape, even if the weight is as small as an ordinary wire paper clip. This effect can be calculated mathematically from the weight of the paper clip and there is agreement between the observations and the calculations to about the one fifty-millionth part of the total length of the tape.

Tests on the hardness of different portions of tapes are now being made on a group of tapes, as a preliminary investigation indicated that certain variations in the uniformity of the material which might render

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the tape unsuitable for the highest precision could be detected by changes in hardness.

A compilation of data on all the base-line tapes which have been tested at the Bureau in the last twenty years is about completed. It is hoped that these data, together with similar data being assembled in other countries, will be of service in securing the highest possible accuracy in the standardization and use of base-line tapes.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

FIRST-ORDER LEVELING

H. G. Avers

The general plan of extending the first-order level net of the United States has been to locate the lines in such a way that eventually no place in the country will be more than fifty miles from a standard bench mark.

In prosecution of this plan, 50,000 miles of first-order levels have been run by the U. S. Coast and Geodetic Survey, the U. S. Geological Survey, the Corps of Engineers, U. S. Army, the U. S. Lake Survey, the Mississippi and Missouri River Commissions, and a number of the leading railroads. The work enters every State of the union but one—Delaware—and forms over one hundred circuits.

During the past year lines were run in South Dakota, Colorado, and California, but only one line will be mentioned in particular at this time.

At the request of the Seismological Committee of the Carnegie Institution, a line of first-order levels was started at the 8,400-foot contour on the slope of Mt. Whitney, California. The work was extended downward across Owens Valley and up the slope of the Inyo Mountains to the 5,000-foot contour. An attempt was made to carry the line to the top of Mt. Whitney, but the work had to be abandoned because the trail leading to the summit was made impassable by rock slides. By rerunning this line at some time in the future it will be possible to determine if there has been any relative movement between the valley floor and the mountain masses.

Representatives of the Geodetic Survey of Canada and of the U. S. Coast and Geodetic Survey recently held a conference at Ottawa, Canada, for the purpose of discussing the problems affecting the first-order level nets of the two countries. The greatest need at present is the adoption of common elevations for the junction points. The level nets have fifteen junction points distributed along the international boundary, and their elevations, as determined by each country, differ from a small fraction

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of a foot to over a foot in some cases. This condition is causing great inconvenience to engineers and surveyors who have to use the elevations, and no little embarrassment to the International Boundary Commission who desire to publish the elevations.

The condition at Rouses Point, New York, is outstanding. The elevation of one of the bench marks at that place was used as the basis for the elevations of all the leveling in eastern Canada. In recent years a number of new level lines were run into Rouses Point, with the result that there is now an extreme difference of 1.3 feet in the various determinations of the elevation which, if the present elevation were held, would have to be taken up by the new leveling. This closure is much too large for the short lines of leveling involved. The leveling to the south and west of Rouses Point has been revised by the Coast and Geodetic Survey and it is believed to be free from error.

It was thought possible to relieve the condition around Rouses Point by adjusting the eastern portion of the Canadian net with the United States leveling in the New England States and in northern New York. An adjustment of this combined work was made by the Geodetic Survey of Canada about a year ago, but the results were not satisfactory as the corrections were far in excess of the average usually applied to this class of leveling.

At the junction points west of Lake Superior, along the 49th parallel of latitude, the elevation differences are on the average about one foot. This is the region where the International Boundary Commission is especially interested and where the need for common elevations is immediate. In this region it was decided to distribute the closures on the tie lines between the two nets. It is believed that the resulting elevations for the boundary points will agree within a very small fraction of a foot with the theoretically best elevations obtained from any latter adjustment.

Of course, the best way to bring about an accord in elevations along the boundary would be to make an adjustment of the combined nets. Plans are now in preparation to do this eventually, but it is believed best to run some additional leveling before taking up the work in order to provide sufficient strength to hold the elevations for an indefinite period.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE READJUSTMENT OF THE FIRST-ORDER TRIANGULATION IN THE WESTERN HALF OF THE UNITED STATES

O. S. Adams

At the meeting of the Section of Geodesy held last April, a report was given of the general plan for the readjustment of the first-order

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triangulation in the western part of the United States. This plan was conceived by Major Bowie and formulated by him in a general way early in 1924. We shall now give some account of the practical application of this Bowie method to the extensive scheme of triangulation west of the 98th meridian, inclusive of the arc along this meridian.

The first step in the general scheme is to adjust a figure at the junction of two arcs, so that a length and azimuth of a line may be determined that is to be held fixed in the adjustment of the section ending with this line. In the ideal junction figure, a measured base should be found and an observed Laplace azimuth. In some cases, where such conditions are found, the junction figure may consist of a couple of quadrilaterals; in other cases, a more extensive figure has to be used, because of the rather involved figures in the triangulation.

When a measured base or Laplace azimuth is not found in the figure that must serve for a junction, it becomes necessary to adopt a length or azimuth, or both if neither is found in the figure, to serve as control in the adjustment of this part. If a length is needed in the figure, the length of some convenient line is computed from the various adjacent measured bases in the adjoining sections and then a weighted mean of these various lengths is adopted as the length for control in the junction figure. In general, the various computed lengths are weighted inversely as the strength of the figures through which the computations are carried. If the azimuth has to be determined in the figure, the necessary procedure is somewhat similar. The azimuth of some line is computed from the nearest Laplace azimuths in the adjoining sections, and a mean of these various values, weighted inversely as the number of angles used in the computation of the given value, is taken as the controlling azimuth in the junction figure.

After the junction figures are adjusted with fixed lengths and azimuths, the various sections between these arc intersections are adjusted, holding all measured lengths and Laplace azimuths, as also the length and azimuth of the line fixed in the junction figure. Since no conditions are introduced for the closure of loops, there will be outstanding discrepancies of this kind wherever two sections meet in which the geographic positions are computed by different routes. It will then be necessary to apportion these discrepancies among the various sections, so that no undue amount is given to any section to be absorbed by closure conditions. This end can be accomplished by apportioning the closures between the sections with the weight of each section being taken inversely to its length. This amounts to an apportionment of the discrepancies just as discrepancies in a level net of the first order are distributed. By one set of equations the latitude discrepancies are apportioned, and by another independent set the longitude discrepancies are distributed to the various arcs.

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At present, about three-fourths of the preliminary adjustment work has been completed and several loop discrepancies have been computed. These discrepancies vary from fifteen feet to thirty-six feet, depending on the size of the loop, but in no case is the discrepancy as much as one part in 150,000 of the length of the loop.

To complete the general scheme, two short arcs have to be observed during the summer of this year. A short section of the Canadian-United States boundary in the northwestern part of the State of Washington has to be completed and an arc extending from Santa Barbara Channel, in California, across the Sierras, to join an arc in Nevada, has to be observed. We expect to be able to determine the most probable positions of the junction points by the end of this year. After that, the various sections can be adjusted to hold these fixed positions in the junction figures.

U. S. Coast and Geodetic Survey,
Washington, D. C.

PRELIMINARY REPORT ON THE USE OF A TUNING FORK IN GRAVITY MEASUREMENTS

PAUL R. HEYL

Abstract.—If it were possible to use a tuning fork as a standard of time, the process of making gravity observations would be much quickened. Two causes of variability in the tuning fork are to be considered: temperature and amplitude. Temperature can be controlled, or at least allowed for, more readily than amplitude can.

Forks of various materials have been studied, and it has been found that magnesium appears to be a promising material.

In order to follow up this question, it is necessary to push the rating of a fork much farther than has been the customary practice.

Bureau of Standards,
U. S. Department of Commerce.
Washington, D. C.

A METHOD OF COMPARING THE FREQUENCIES OF A PENDULUM AND A TUNING FORK

PHILIP P. QUAYLE

Abstract.—This paper describes a method of obtaining a permanent record of the vibrations of a tuning fork against a free pendulum. The apparatus consists of a Coast and Geodetic Survey quarter-second pendulum fitted with special knife edges which are illuminated by a 400-watt projection lamp. The flashes thus produced fall upon a potassium hy-

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droxide photo-electric cell. The few micro-amperes of cell current are amplified by means of a suitable resistance coupled amplifier in order to operate an oscillograph element. This element records its motion on the film of a special high speed camera, giving a record 40 feet in length.

With the apparatus in its crudest form, the probable error of the mean of the fork vibration over four successive seconds due to whatever causes does not greatly exceed one part in 50,000.

With this method it is not necessary to have an approximate calibration of the fork or, in fact, to know anything about it.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

USE OF THE GRAVITY PENDULUM AS A TIMEPIECE FOR LONGITUDE DETERMINATIONS

E. J. Brown

Longitude determinations of a precise nature are made by measuring the difference in longitude between a point of unknown position and a point whose position has been very accurately determined. The longitude difference can as well be expressed as a time difference and is, in fact, so measured, and it is evident that the accuracy with which the time difference is known is the sole factor determining the accuracy of the results of the longitude observations.

The modern method of measuring differences in longitude is to compare time as obtained by local star observations with a radio time-signal sent at a known time from a point of known longitude.

In the actual observations, a ship's chronometer is used as a timepiece and a clock error is determined by star observations both before and after the reception of the radio signal. Using the two errors thus found, a clock rate can be computed and an interpolation made for the clock error at the instant of reception of the time signal. It is evident that any error in the value of the clock rate determined will directly affect the longitude results. To keep this error within desirable limits, it is necessary to make the star observations in as short a time as possible in order that the chronometer need not be depended on to carry time for any long interval. The ordinary ship's chronometer, when operating under wide ranges of temperature, as is usually the case in the field, will not carry time with sufficient accuracy for more than an hour. If, then, it becomes necessary to make star observations several hours before or after the radio signal is received, it is obvious that a more accurate timepiece must be used.

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During the meeting of the Section of Geodesy of the International Geodetic and Geophysical Union at Madrid, in 1924, this very problem confronted the committee drafting plans for a proposed world-girdling longitude survey. This survey, which is to take place in October and November of this year, necessitates the reception of time signals from at least two different stations, with a probability of as much as five hours intervening between the signals. The committee discussed the question of timepieces at some length and Major Bowie, who was one of the committee members, suggested the use of the gravity pendulum. Later consideration of the suggestion seemed to indicate that it was a very good one, and at present experiments in adapting the gravity pendulum for use as a timepiece are being carried on.

The standard gravity pendulums are of the Von Sterneck type, a half-second, quarter-meter pendulum. The pendulum swings free on agate bearings in an air-tight receiver with the pressure reduced to about 60 mm. So little friction is offered to the movement of the pendulum that when started with a double amplitude of 8 mm. it will have a double amplitude of 2 mm. or more at the end of a 12-hour swing. Mirrors mounted on the pendulum head and support enable the pendulum oscillations to be counted by means of the flash-coincidence method, using two ships chronometers as timepieces. The chronometers are rated by comparison with radio time-signals or star observations.

The present method of gravity determination gives the period of the pendulum to a millionth of a second. This means that the error due to the pendulum in carrying time over a 3-hour period would be of the order of .002 or .003 second. A ship's chronometer may vary as much as .05 second in the same length of time. This comparison of errors shows the pendulum to be far superior to the chronometer as a timepiece, and its adaptation for use in the longitude observations will greatly increase the accuracy of the determinations as well as remove some of the restrictions in regard to the time at which star observations may be made. The elimination of the necessity for making the star observations so near to the time of reception of the time signals is especially desirable. Clouds will often obscure the stars for two or three hours and if the time signal comes during this period the night's work is lost. During the past field season time signals were sent from Annapolis at noon and 10 p. m. It was necessary, of course, to use the night signal in connection with the longitude observations. Atmospheric disturbances during a period of about two months made recording of the night signals so difficult that many of them were missed. The day signals could usually be recorded with ease during that period, and had it been possible to carry time from the noon signal until dark the observations could

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have been made without the use of the night signal, thereby saving a great deal of time.

In adopting the pendulum for use in the longitude work no attempt is being made to do away with the chronometer altogether, and to use the pendulum as an absolute timepiece. It is proposed, rather, to use the pendulum as a means of keeping a very accurate check on the chronometer rate. This could be accomplished by making comparisons between the chronometer and the pendulum by the coincidence method, using the gravity flash apparatus. The flash apparatus, however, has proved to be somewhat faulty in operation, owing to the varying value of the time lags caused by friction of the moving parts, and it is believed that a photographic method of recording the coincidences will give greater accuracy and will also have the advantage of leaving a permanent mechanical record.

The apparatus being constructed will afford a means of tracing the pendulum oscillations on slowly moving film or photostatic paper. By means of a shutter in the clock circuit a break is made in the record at each second break of the chronometer. The point of coincidence can be taken at the extremity of the swing and there should be no trouble in picking it to the nearest second. The half-second pendulums lose a beat on a sidereal chronometer about once in five minutes, consequently an error of one second in picking the coincidence will cause an error in the comparison of but 1/300 second. By making comparisons at frequent intervals a very accurate check will be had on the clock rate and the longitude results will be but slightly influenced by the quality of the chronometer. The probable error in determining a time interval, even of several hours, should be little greater than .01 second.

The use of the free swinging pendulum in connection with the longitude observations will not be its first adaptation to other than gravity work. The Bureau of Standards is using the gravity pendulum as a standard timepiece for testing the qualities of tuning forks, and Professor Michelson is using the pendulum in connection with his work in determining the velocity of light. The results obtained from the pendulum in these experiments have been very good and have demonstrated the effectiveness of the apparatus in keeping time over short intervals.

U. S. Coast and Geodetic Survey,
Washington, D. C.

RECENT DETERMINATIONS OF GRAVITY AT SEA

C. H. SWICK

At a previous meeting of this Section, I told you very briefly about some gravity determinations at sea made by Dr. Meinesz, of Holland,

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Engineer to the Dutch Geodetic Commission. You remember he used an ordinary Stückrath pendulum apparatus, but made his observations in a submerged submarine and recorded the oscillations of the pendulums photographically. In the summer of 1923, on a trip from Holland to Java through the Mediterranean Sea and the Suez Canal, Dr. Meinesz made about thirty gravity determinations at sea with an accuracy much greater than had ever before been attained at sea.

Recently he has completed another series of sea determinations on a trip from Holland to Port Said, Egypt, over a part of practically the same route followed on the first trip. In the 1923 work Dr. Meinesz found large positive anomalies in certain deep parts of the Mediterranean Sea, and he was anxious to make additional observations over these areas both to test the accuracy of his first determinations and also to obtain additional information in the critical areas. Owing to the international character and value of this work and in response to the urgent request of Dr. Meinesz, the Director of the Coast and Geodetic Survey has promised that the isostatic reductions of these new determinations, as was done for the first series, will be made by mathematicians of the Coast and Geodetic Survey.

Another very important object of these recent determinations was to test out thoroughly a new type of gravity apparatus recently perfected by Dr. Meinesz.

The old Stückrath apparatus, as you will remember, has four pendulums and these oscillate in two pairs of parallel vertical planes, the two pairs of planes being at right angles to each other. In using this apparatus on his first trip, Dr. Meinesz swung all four of these pendulums simultaneously and obtained an independent photographic record of the oscillations of each. By combining the records of each pair of pendulums swinging in parallel planes he was able to compute the period of a hypothetical pendulum, which period was free from any effect of the horizontal acceleration of the ship. The computation of this hypothetical pendulum was a very laborious process which consumed a great deal of time and required almost unlimited patience.

The new apparatus designed by Dr. Meinesz has only three principal pendulums instead of four and these all swing in the same plane, perpendicular to the longitudinal axis of the ship. It has a very ingenious arrangement of mirrors, by means of which the beam of light used in making the photographic record is reflected from the middle one of the three pendulums onto each of the two outside pendulums before it reaches the recording film. In this manner there is obtained directly on the record, and with no computation required, a combination of the oscillations of the middle pendulum with the oscillations of each of the other two, or what might be termed their relative oscillations. The record.

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therefore, shows the oscillations of two hypothetical pendulums, and these are free from the effect of any horizontal acceleration of the ship.

In addition to the three principal pendulums just mentioned, the apparatus includes also two shorter auxiliary pendulums, both heavily damped. One of these measures the deviation from the vertical of the plane of oscillation of the principal pendulums or, in other words, the end-wise tilt of the knife edges on which the pendulums swing, which should be kept within certain prescribed limits. The other auxiliary pendulum measures the amplitude of oscillation of the middle one of the three principal pendulums by recording the angle between the axis of this pendulum and that of the damped one. This record is used in computing the correction for amplitude of oscillation to be applied to the final results.

Very accurate results are obtained on a submarine with the new apparatus, and there is a possibility that it can be used on an ordinary surface ship also. In about a month from now Dr. Meinesz will leave Holland on a submarine of the Dutch Navy, which will take the western route to Java, passing through the Panama Canal. He will use his new apparatus and expects to obtain a large number of gravity determinations in both the Atlantic and the Pacific Oceans during the six months required for the trip. The Coast and Geodetic Survey has loaned him one of its new radio recording sets which he will use in obtaining the rates of his gravity chronometers.

The results obtained on this trip will be of very great interest and value to geologists and geodecists. They will give the first accurate knowledge of variations of gravity over the two great bodies of water, the Atlantic and the Pacific, and will make possible a more complete test of the theory of isostasy than has ever been made. They will also furnish a very important test of the longitude term of the gravity formula derived by Helmert, Heiskanen, and others.

At the conclusion of this trip Dr. Meinesz will have circled the globe with his accurate gravity measures at sea. This is a pioneering accomplishment nearly as wonderful from a scientific standpoint as Magellan's was from a geographic.

U. S. Coast and Geodetic Survey,
Washington, D. C.

THE TREND OF GEODESY

WILLIAM BOWIE

For many years geodesy was considered to be a science devoted only to the determination of the shape and size of the earth. In general the operations necessary to make such determinations were base measurements, triangulation, and the determination of astronomic latitudes,

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longitudes, and azimuths. The first geodetic work of any importance was the triangulation in Lapland and Peru to test Newton's view that the shape of the earth was that of an oblate spheroid. There was also an important piece of geodetic work involved in the extension of the French arc from which the shape and size of the earth were derived in order to establish the metric system.

Aside from the value of the triangulation and astronomic determinations of latitude, longitude and azimuth in the determination of the size and shape of the earth, the resulting data proved to be of the greatest value in correlating the surveys from which charts and maps of large areas were constructed.

The determination of the shape of the earth, but not its size, has frequently been made from value of gravity observed at widely separated points over the earth's surface, although this line of attack for the shape of the earth came much later than did the one which uses triangulation and astronomic data.

It was in trying to derive a figure of the earth from triangulation data that an important geophysical fact was discovered, that is, that mountain systems do not deflect the direction of gravity to the extent that the mass of the mountains would indicate. In the 1850's Airy and Pratt, working on geodetic data of India, arrived at the conclusion that under mountain systems there is a deficiency in density which supports or floats the portion of the crust involved in the mountain area. This deficiency, extending for an unknown depth below the earth's surface, has the effect of reducing the attraction of the mountain. It was from these studies of Pratt and Airy that the theory of isostasy was developed by Major C. E. Dutton of the U. S. Geological Survey in the 80's. His paper setting forth his theory was delivered at a meeting of the Philosophical Society of Washington on April 27, 1889, under the title "On some of the greater problems of physical geology." It was first published in the Bulletin of the Philosophical Society of Washington, vol. XI, 1892, pp. 51-64. As the edition was exhausted with the passage of years, the article, on account of its great importance, was reprinted in the Journal of the Washington Academy of Sciences, September 19, 1925, vol. 15, no. 15.

Dutton paved the way for geodesy to enter a much broader field than it had previously occupied. The whole question of earth physics is now more or less directly connected with geodetic observations and deductions. It may be said that the trend now of geodesy is along geophysical and geographic lines, in addition to purely dimensional ones which involve the shape and size of the earth.

About twenty-five years ago the Coast and Geodetic Survey entered on a vigorous campaign to test the theory of isostasy as outlined by Dutton. Some field work had been done during the 90's by that bureau, but the

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results were inconclusive. The theory of isostasy was proved to be true and it may now be considered as a scientific principle or fact. Briefly stated, isostasy forces us to believe that the earth's crust is resting on what might be termed isostatic equilibrium on a subcrustal material that has little or no residual rigidity. A crust, on the other hand, has residual rigidity, as is proved by the fact that it can maintain a surface of unequal elevation. The theory of isostasy has been tested in widely separated areas with excellent results in every case. We seem to be justified in assuming that isostasy prevails throughout the earth's crust. With isostasy proved, the geodesist has been forced into a broader field covering geology, seismology, volcanology, and oceanography.

It may be said by some that, since the geodesist has proved the theory of isostasy to be a fact, anything else that is done towards applying isostasy to earth studies would be outside the realm of geodesy. But can this be true? I think that almost any study that is necessary in extending isostatic investigation beyond the mere proof of its existence may be legitimate geodetic work. We need to know to what extent isostasy applies to local topographic features. We need to know also how isostasy is maintained, what was the condition of the earth's crust at the beginning of the sedimentary age and what are the rates of vertical and horizontal movements of the past on the earth's surface. All of these, surely, are involved in the study of isostasy. Is not this another case of the boundaries between what we call separate and distinct sciences being removed? It is practically impossible today to draw separate lines between any of the sciences. Chemistry and physics are considered to be practically one and the same thing. The physicist is required to know much of chemistry and the chemist certainly must know much of physics.

For many years the variation of latitude has been considered a geodetic problem, although it is also an astronomical one. The geodesist, whose classical function is to determine the shape of the earth from triangulation and astronomic data, must know whether the axis of rotation of the earth and the axis of figure are the same or, if not, what their relationship is. Does it remain fixed, or is it variable? The International Geodetic Association, many years ago, attempted to solve these problems by the establishment of five variation of latitude stations, all placed along the 39th parallel of latitude in various parts of the world. Three of these stations, in Italy, Japan, and the United States, have been operated continuously for more than 25 years. One, also in the United States, was abandoned just before the war. The fifth, in Turkestan, was abandoned a few years ago.

From the variation of latitude data we are able to determine the elastic properties of the earth as a whole. Thus a phase of geodetic work becomes practically geophysics in the general sense of the latter term.

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The geodetic work, in the form of triangulation and leveling, has been greatly extended in its use until today the engineer engaged on charting, surveying, and mapping and in many of the engineering problems of the country requires the accurate elevations and geographic positions furnished by geodesists.

We may summarize the situation by saying that geodetic work is taking its place with other earth sciences in solving the problem of why we have changes in elevations and geographic positions on the surface of the earth and that geodetic data are becoming of great value in industrial development. What was once a narrow field has become a very broad one.

U. S. Coast and Geodetic Survey,
Washington, D .C.

EXCESSIVE CASES OF LATERAL REFRACTION

J. L. RANNIE

Lateral, or horizontal, refraction is quite frequently encountered in the angular measurements of triangulation systems, but its occurrence is usually spasmodic and may usually be attributed to air currents or pockets on lines in proximity to buildings, mountain masses, etc. Two cases of consistent lateral refraction have occurred in Canada which permit the underlying causes in these cases to be investigated and, perhaps, explained.

An extended and persistent example of lateral refraction was met on the triangulation net of the St. Lawrence River and Gulf, the field work of which covered some 325 miles and extended over four seasons. In this net the lines along the river bank were so consistently "bent" *towards the river* that a practice had to be adopted of ending observations on these lines only when the results on at least two nights showed a satisfactory agreement. Lateral refraction affecting the observations by from 5 seconds to 15 seconds of arc was not at all uncommon, and it has been estimated that almost three times the amount of clear weather ordinarily necessary to secure the required program of observations was used to secure the required accuracy. Even with the precautions which were taken, the evidence shows a regular bending *towards the river* of the lines parallel to the river. This is evidenced by the error of closure of triangles, the sum of the three observed angles being less than the theoretical sum in the majority of cases.

From an illustration showing curved lines exaggerating the "bent" condition of the lines parallel to the river, it is obvious that the sums of the angles of all of the triangles of which the figures are composed would be less than they should be. The following table was compiled from the closure errors of the triangles used in the adjustment of this large net:

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	Number	Average error
Triangles in which sum of angles was too small.....	42	—1."107
Triangles in which sum of angles was too large.....	12	+0."700

Had only accidental errors entered into the measurement of the angles of this net, approximately the same number of positive as negative closing errors would have been expected. The last column indicates that even where the sum of the angles was too large, the errors were probably reduced by the "bending" indicated above. This information may be stated in another way. In the adjustment of this net the large majority of the corrections to lines parallel to the river "unbent" these lines away from the river.

	Number	Average correction
Corrections which "unbent" lines away from river..	54	0."450
Corrections which produced opposite effect.....	12	0."257

This table indicates a great preponderance, both in number of bent lines and magnitude of the correction. In contrast to this tendency of the lines parallel to the river to bend towards the river, the adjustment gave to lines crossing the river 62 positive corrections averaging 0."343 and 61 negative corrections averaging 0."316. The errors on these lines are clearly of an accidental, rather than a constant, type.

A superficial explanation of the persistent occurrence of lateral refraction in this area is probably that the strata of air of different density frequently did not lie horizontal, as is generally assumed, but followed more or less closely the surface of the land. Lines along the hilly shore passed through strata which dipped towards the river, and the plane of the curved path of the ray of light, being perpendicular to the strata, was inclined towards the river. The light, hence, appeared above, and slightly to the river side of its true position instead of directly above, as would be the case were the strata of air horizontal. This theory accounts for the fact that on the lines across the river no evidence of horizontal refraction existed.

The season of 1925 provided further examples of the persistent occurrence of this phenomenon and permitted the underlying causes in certain cases to be still further investigated. During the hot weather, in the course of the measurement of a precise traverse on the railway tracks along the Skeena River in British Columbia, aggravated cases of lateral refraction occurred. In this case the lines were "bent" *away from the river* and towards the hills, just the opposite to the effect in the St. Lawrence River area noted above.

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The railway runs in a general east-and-west direction along the north bank of the river at the base of cliffs many hundreds of feet high. The sun, therefore, shone on these cliffs during most of the day. Traverse courses were short, owing to the excessive curvature of the railway line, varying from 100 to 2,000 meters. An azimuth line connected stations about 5 miles apart, so that loops were formed which permitted the error of closure to be measured. Measurement of traverse angles made in strong sunlight consistently showed that the traverse lines were "bent" *towards the cliffs,* the angular error increasing with the length of the line. Re-observation of the angles at 65 traverse stations at night or on dull days disclosed errors of from three to five seconds on 100- to 200-meter lines and up to 20 seconds on lines near a mile in length. The sign of the error in all cases showed the lines to have been "bent" towards the cliffs.

The explanation advanced is that the air close to the cliffs became super-heated, much expanded and hence less dense than the air at equal elevations over the river. The layers of air of equal density or pressure therefore dipped as they approached the cliffs.

The refracted course of the rays of light passing through these layers of air of different density may have been tilted from a vertical even to a horizontal plane. Even in such a case the coefficient of refraction must have been from 0.2 to 0.5 to have produced the above effects, a very excessive figure.

The foregoing interpretation may be used to further explain the tilting of the air strata which was found in the St. Lawrence River area. The observations in this district were made on lights at night, when the land surface was cooling rapidly. This cooling would produce a contraction of the air with consequent greater density, and, as the land became cooler than the very large body of water, the strata of air of equal density would tilt upward towards the hills and produce the lateral bending so consistently noted.

Under this theory it might have been anticipated that the above "bending" of the lines towards the St. Lawrence River would not have occurred had the lines been observed in the daytime. Indeed the effect might have been the reverse on hot days.

Geodetic Survey of Canada,
Ottawa, Canada.

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SECTION OF SEISMOLOGY

(Washington, D. C., April 30, 1926)

MINUTE COOLING EFFECTS REVEALED BY THE SEISMOGRAPH

E. A. Hodgson

The effects referred to were first observed at the Dominion Observatory, October 11, 1916. They consisted of rhythmic oscillations of a cement pier, following the disconnection, after a long period of equilibrium conditions, of a small electric heater, placed in the underground vault in which the pier in question supported a "Deformation Instrument" or tilt-measuring seismograph.

A series of experiments followed, which continued to December, 1920. A paper describing these was given, by title only, before the American Physical Society and Section B (Physics) of the American Association for the Advancement of Science, at the Chicago meeting, December 28-30, 1920. An abstract of this lecture was given in the Physical Review, vol. XVII, March, 1921, pp. 376-377. A complete account of the work was published as one of the series of Publications of the Dominion Observatory, Ottawa (vol. V, no. 2), with the title, The Effect of Cooling on a Cement Pier.

The publication, which is fully illustrated, describes the methods used to make certain that the oscillations of the light spot on the recording drum were caused by the movements of the pier and not through variations in the parts of the instrument. An attempt was also made to determine the nature of the movements of the pier and their magnitude.

By a specially arranged device, the sensitivity to tilt of the deformation instrument was shown to be such that, for the free pendulum period used (30 seconds), one millimeter displacement of the light spot on the record indicated a tilt of .0075 second of arc.

The experiments were not successful in determining the exact nature of the movements. It was not shown whether they were due to impulses, to tilts, or to torsional oscillations. If we assume that they were entirely due to tilt, the magnitude was of the order of a tenth of a second of arc for most of the sustained patterns on the record.

In February and March, 1922, an effort was made to find out how long the oscillations would continue. The heater was turned off and left off for five weeks. The cooling was slow and continuous for that period, as shown by a small Richard thermograph. The oscillations continued for the whole time. The "resonance pattern" (if one may so designate the regular sequence of excursions of the recording light spot) changed slowly from one form to another.

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In the complete report the prediction is made that mountain peaks may be expected to oscillate when cooling after a hot afternoon sun has been warming up their western slopes.

The St. Lawrence earthquake of February 28, 1925, drew the attention of the Dominion Observatory to the need of a seismograph in that area. Accordingly a Milne-Shaw instrument was installed at Ste. Anna de la Pocatiere (on the south side of the St. Lawrence, about 90 miles below Quebec). Pending the drying out of the valley, a temporary station was obtained in the basement of the Agricultural School. This building rests on a flat shelf cut into the rock near the base of an outcrop of rock, approximately 150 feet high and of the proportions of a miniature mountain. The seismograph was mounted on the floor of the basement, which in turn was built directly on the rock.

April 10, 1925, was an unusually warm day, followed by a frosty night. The prediction was made that oscillations of the mountain would appear on the record. They did appear. The cooling caused a tilt which, strange to say, did not appear until nearly midnight. This was probably due to the location of the school, which was on the east side of the mountain and at its very foot. The oscillations began about 4 a. m. on April 11, and continued with approximate regularity for three hours. At that time their recording was interfered with by the boom fouling the bumper post.

These oscillations, if we interpret them as being due entirely to tilt, indicate a maximum flexure of .01 second of arc. The complete period of a cycle was about 80 seconds. The amplitude and period were both decreasing slightly when the movement was interfered with by the bumper stop.

Further experiments, both in the laboratory and in the field, are contemplated.

Dominion Observatory,
Ottawa, Canada.

NEW SEISMOLOGICAL TABLES

JAMES B. MACELWANE, S. J.

The title of the present paper on which the writer was asked to speak at this meeting of the American Geophysical Union has undoubtedly aroused in the minds of many the question of the necessity or advisability of new tables for earthquake waves. Why not standardize our results by adopting officially one of the sets of tables now in use instead of adding to the confusion by issuing new ones?

In 1903, John Milne[1] issued a set of tables in which he postulated

[1] B. A. Report, 1903, p. 84; also, Nature, vol. 67, April 9, 1903.

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an outer mantle and an inner core, in both of which the velocity was assumed constant. In 1905 H. Benndorf[2] issued tables which were more nearly in accord with observation. He has the merit of being the first to call attention to evidence for a discontinuity at slight depth. His tables placed this break in the velocity of earthquake waves at a depth of five hundred kilometers. From there downward he postulated gradual increase of velocity. In 1906 R. D. Oldham[3] published tables which reverted to the hypothesis of a chordal path and constant velocity. But in the following year the well-known tables of Wiechert and Zoeppritz[4] were published. These mark a new era in seismometry. Another such epoch-making addition to our knowledge of travel times was the publication in 1909 and in 1914 of the researches of the two Mohorovičićs. In 1916 Otto Klotz combined these results in his Seismological Tables.[5] These tables are still in quite general use. Some combinations in them are unfortunate, particularly the travel times for PS, which are quite incorrect and make the transformed waves arrive before the direct transverse waves. This would seem to have come about by adding travel times for P and S for half the distance, thus neglecting Snell's Law for the angles of reflection. The transverse wave reflects at a lesser angle than the longitudinal, hence it goes deeper, and traverses a longer path than the longitudinal reflected wave. More recently, the Seismological Committee of the British Association[6] has issued tables for P,S, and S-P both in single degrees and to a great extent also in tenths of a degree up to 150° distance. But the curve for the travel times of P goes over into P′ and that of S into PS in the second quadrant. None of these tables can be expected to embody the recent observations on refracted and diffracted waves at great distances, and hence on the effect of proved discontinuities and of the core. The only tables which do take account of these factors are those of Gutenberg, 1914[7] and 1923,[8] those of A. and S. Mohorovičić, 1914,[9] 1921,[10] and 1925,[11] of Angenheister, 1921,[12] and with somewhat less precision, those of S. W. Visser,

[2] K. K. Akad. der Wiss. in Wien, Mitteilungen der Erdbebenkommission. Heft 29. 1905; Heft 31, 1906.

[3] Quart. Jour. Geol. Soc., vol. 62, p. 456.

[4] Nachr. der k. Ges. der Wiss. zu Göttingen, math.-phys. Kl., 1907.

[5] Publ. of the Dominion Observatory, vol. 3, no. 2, Ottawa, 1916.

[6] International Summary.

[7] Nachr. der Ges. der Wiss. math.-phys. Kl. 1914.

[8] Sieberg-Gutenberg, Erdbebenkunde, pp. 288-291.

[9] Bull. of the Acad. of Sci. and Arts of Jugoslavia, July, 1914, and manuscript.

[10] Acad. of Sci. and Arts of Jugoslavia, May 20, 1921, pp. 94-190.

[11] Publications du Bur. Centr. Seism. Intern., Ser. A, Travaux Scientifiques, fasc. 3.

[12] Nachr der K. Ges. der Wiss. zu Göttingen, math.-phys. Kl., 1921.

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1921.[13] Recently an average table was published by G. Krumbach.[14] None of these are entirely complete or very closely interpolated.

Now there has been felt for many years the need of tables which would give at a glance the travel times of all the earthquake wave groups or phases which may be expected to arrive at a station situated a given distance from the epicenter of any earthquake. Such tables can be constructed by listing travel times for successive phases in parallel columns so that all those for any given distance appear on one horizontal line.

It was on that model and with this need in view, in 1911, that the Reverend Joseph S. Joliat, S. J., and the writer constructed and published in the Bulletin of Saint Louis University,[15] a table for the arrival times of phases up to an epicentral distance of 13,000 kilometers. That table was based on the most reliable data then available, particularly those of Wiechert and Zoeppritz, and gave distances in megameters, miles and degrees, but it was not interpolated more closely than to intervals of one hundred kilometers and is now, of course, obsolete.

In the summer of 1923 Dr. Perry Byerly and the writer, at the University of California, made up another set of tables which were distributed to a few friends for trial and were referred to by Dr. Byerly in the Bulletin of the Seismological Society of America.[16] These tables were far more elaborate than those of 1911 and form the model and groundwork of the new tables which have just been completed.

In the first place, in 1923, the question arose as to whether the tables should be built on kilometers, as most previous tables had been, or on degrees of arc as the British tables were. Dr. Byerly and the writer were doing so much work with a thirty-six inch globe at the time that we decided at once for one-tenth of a degree as our unit of distance. However, it is necessary very frequently to give the number of kilometers and in this country also of miles. Conversion from one to the other is always troublesome, and to avoid the necessity of it we decided to calculate and embody a conversion table in our set. This has been retained.

We decided to include travel times for the direct longitudinal and transverse waves and for three of their reflections, for both the surface groups of greatest prominence, the L or long, irregular waves at the beginning and the M or shorter, larger, more regular waves that follow, and finally for the returns of the surface waves, the W_2 group which

[13] Verhandelingen, No. 7, Kon. Magnet. en Meteor. Observatorium te Batavia, 1921.

[14] Zeitschr. für Geophysik, Bd. I, H. 8, Oct. 1925.

[15] Vol. 7, no. 5, pp. 23-25.

[16] Vol. 14, pp. 96-97.

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travels by the longer arc and the W_s group which arrives a second time after a complete circuit of the globe.

The travel time curves for the surface groups L and M were constructed by plotting for the former more than twelve hundred points and for the latter about eleven hundred points, representing observations of travel times as a function of distance and then drawing through the points thus plotted in each case an average curve. The velocity obtained for the L waves was 3.93 kilometers a second and for the M waves 3.42 kilometers a second. The latter figure is not far from the velocity, 3.46 kilometers a second, Cavasino [17] found for the return waves, and it happens to be exactly that found by Angenheister [18] in 1906. The 1200 and 1100 observations used by us were carefully selected for their reliability from the lists in the British Association Summary.

However, the great mass of excellent observations which have become available since the summer of 1923 has made it advisable to reconstruct the parts of the table which refer to the preliminary phases. This was done at St. Louis University during the past months. The travel times for the normal longitudinal and transverse waves published by the Mohorovičićs in 1921 have proved so near an approximation to reality under trying tests that they have been included bodily and all time differences have been referred to them. The travel times for some of the reflections and for all of the core waves have been taken from Gutenberg's 1923 tables. There is nothing at present more reliable.

The tables are divided into four parts. The first part includes the travel times and differences for thirteen phases direct and reflected, for epicentral distances between ten and one hundred and three degrees. The tables begin with a distance of ten degrees from the epicenter, because at distances shorter than this the excellent Mohorovičić-Rothé multiple tables are available for different depths of focus. This varying depth, together with the subcrustal discontinuity, makes the use of a single set of tables for near earthquakes quite impossible.

The second part is composed of travel times, referred to the time at the origin, of sixteen phases between ninety and one hundred and eighty degrees of distance from the epicenter. They are mostly the direct and reflected groups, but include P between one hundred and three and one hundred and forty-seven degrees distance, which is a diffraction phenomenon. They also include P′ between one hundred degrees and one hundred and forty-two degrees where it seems to be a diffraction phenomenon and between one hundred and forty-three and one hundred and eighty where it is a refracted wave coming through the core of the earth.

[17] Boll. della Soc. Sism. Italiana, vol. 23, 1920-21.

[18] Nachr. der Ges. der Wiss. zu Göttingen, math.-phys. Kl., 1906.

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The third part will contain those further waves that have been affected by the core of the earth as far as data are available for them in Gutenberg's 1914 and 1923 tables.

The fourth part is devoted to waves reflected on the further side of the earth.

The tables are being issued in this preliminary form in order that they may be tested, criticized and improved in every way possible before they are finally printed for general distribution.

It is hoped that these tables will stimulate the study of the seismograms of earthquakes at greater distances. Hitherto, they seem to have frightened by their complexity all observers who were not specialists in the science. In fact, until quite recently, the first reports on very distant earthquakes which were issued by many stations were erroneous and misleading, because the observers were looking in the records of remote earthquakes for the phases characteristic of shorter distances and overlooking the obvious earmarks of a very distant shock.

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SEISMOLOGICAL INVESTIGATIONS AND OCEANOGRAPHY

T. WAYLAND VAUGHAN

The results of seismological researches are of significance to the student of oceanography in the same way that they are to any other student of general geophysics. Most of the hydrosphere, one of the shells of material which compose the earth, is contained in the ocean basins, which are bounded above by the atmosphere and below by the lithosphere, two other shells of earth substance. If the student of the ocean wishes to understand the relations of the hydrosphere to the other components of the earth he must pay attention to seismology and studies of earth tides, for those are important sources of information on the internal constitution of the earth.

The ocean covers about 71 per cent of the surface of the solid. On an areal basis, therefore, 71 per cent of the earthquakes would be expected to originate below sea level. It is now known that earthquakes are due to deformation in the lithosphere. Although this deformation may result from several kinds of causes, the most important kind expresses itself in faulting, which usually, but not invariably, produces change in level on the two sides of a fault line. Seismological research, therefore, offers assistance in explaining important features in the relief of the sea bottom and certain features of the ocean margins.

It is now generally admitted that the continents stand high because they are composed of lighter, and the ocean basins lie low because they

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are underlain by denser, material. The contact zones between the lighter continental and denser suboceanic masses are sites of earth strains, the marginal continental rocks tending toward upfolding and the suboceanic rocks toward downfolding. We perhaps need not consider the relative merits of whether the continents are overfolded and overthrust on the suboceanic masses or whether the suboceanic rocks are underthrust with reference to the continental margins. These marginal zones are the sites of important earth movements, in them lie the greatest seismic zones of the earth, and they are of critical importance to the oceanographer.

Certain facts illustrating the relations indicated are too well known to require more than briefest mention. The Pacific Ocean is margined by mountains from southern Chile northward to Alaska, thence by way of the Aleutian Arc to northeastern Asia, and thence southward to the East Indies and on to New Zealand. On the seaward side of the mountains is the ring of Pacific deeps. The zone between mountains and deeps, and probably involving both, is the circum-Pacific earthquake zone. The zone passes westward by way of the Himalayas to the Mediterranean region of Europe and Africa, and eastward it crosses southern Mexico and follows around the Antillean arcs. Throughout most of the vast region sketched in outline, seismology is an essential part of oceanography.

In order to be more specific regarding the close connection between seismology and oceanography, the ocean deeps of the Caribbean region will be cited as instances. Rev. J. Scherer, director of the Meteorologic Observatory of the Seminary-College St. Martial, Port-au-Prince, Haiti, appears to have been the first definitely to have correlated earthquakes with the formation of the Caribbean deeps.[1] The subject has also been discussed by Vaughan, Taber, and Woodring.[2] Woodring interprets the Bartlett Deep as a synclinal trough bounded on the sides by high angle thrust faults, basing his interpretation on analogy with the observable structure of the margins of the Cul-de-Sac Plain of Haiti. All of the interpretations agree in that to faulting is attributed an important rôle in the formation of the trough. Those who may wish to follow the subject in detail may consult the papers listed by Woodring in the volume cited above. Taber is of the opinion that many of the West Indian earthquakes are of submarine origin.

Two instances of the convincing establishment of a submarine site for the origin of West Indian earthquakes will be given. The first is that

[1] Scherer, J., Les tremblements de terre de l'île d'Haiti dans leur rapports avec le relief du sol et les fosses maritimes qui l'entourent: Observ. Météorol. Sém-Coll. St. Martial, Bull. semest., July-Dec., 1912, pp. 132-139, 1913.

[2] Woodring, W. P., Geology of the Republic of Haiti, pp. 331-353, 1924, gives references to literature as well as the results of his own studies.

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of the Virgin Islands earthquakes of 1867-1868,[3] concerning which Reid and Taber say:

"The earthquake and sea waves seem to have been propagated from an origin on the north side of the Anegada channel not far from latitude 18° 10′ north and longitude 65° west, or about fifteen or twenty kilometers south of St. Thomas."

A statement of the evidence on which this conclusion is based is then given in the article from which the quotation above is taken.

The second instance is that of the Porto Rico earthquakes of October-November, 1918.[4] Regarding the site of the origin of these earth vibrations, Reid and Taber says:

"All of the evidence collected is in accord with the conclusion that the earth vibrations and sea wave were propagated from an origin in the northeastern part of Mona Passage. As the seat of the disturbance was under the ocean, at a depth of possibly 1,000 fathoms, it is impossible to determine its exact location; but it could not have been far from latitude 18° 30′ north and longitude 67° 20′ west, or, roughly, fifteen kilometers west of Point Borinquen lighthouse."

The passage quoted above is followed in the original article by a résumé of the facts on which the opinion is based.

I have spent a great deal of time either drawing profiles of the sea bottom in the Antilles or measuring the slopes according to the hydrographic charts. Submarine faulting has been one of the most important factors in determining the character of the sea bottom in the Antillean region.

A large number of instances of the submarine origin of earthquakes in the Pacific could be quickly compiled—they are circum-Pacific—but to do so seems unnecessary for this brief statement.

Faulting in some regions determines the character of the shoreline. An excellent illustration of such an influence is furnished by New Zealand, whose shore features have been admirably studied by C. A. Cotton.[5]

It is hoped that the foregoing summary statement has made clear that seismology can be regarded almost as a branch of oceanography, because seismology is one of the most important sources of information on the constitution of the interior of the earth, and it is necessary for understanding important features of the relief of the sea bottom and for interpreting the origin of certain types of shoreline topography. Every oceanographic institution should have as a part of its equipment properly in-

[3] Reid, H. F., and Taber, Stephen. The Virgin Island earthquakes of 1867-1868: Seismol. Soc. Amer. Bull., vol. 10, pp. 9-30, 1920.

[4] Reid, H. F., and Taber, Stephen, The Porto Rico earthquakes of October-November, 1918: Seismol. Soc. Amer. Bull., vol. 9, pp. 95-127, 1919.

[5] Cotton, C. A., Geomorphology of New Zealand, pp. 430-435, 1922. For additional references see bibliography on p. 452.

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stalled and operated seismographs, and these and an automatically recording tide gauge should be tied into the same system for recording time, for seismographs and tide gauges are mutually complementary instruments.

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RELATION OF EARTHQUAKES TO ISOSTASY

WILLIAM BOWIE

While the isostasist can assist the seismologist in the study of earthquakes, their cause and effect, at the same time the seismologist can be of great assistance to the isostasist.

With the proof of isostasy, we are led to believe that the earth's crust must be quite weak in order that the adjustment may be so nearly perfect as has been found.

The earth's crust has been found to be of the order of magnitude of sixty miles in thickness. This depth was determined mathematically from the consideration of the differences between the theoretical and the observed values of gravity and the theoretical and observed deflections of the vertical. Such a depth as has been found is an average and it is reasonably certain that the compensation extends in places below sixty miles.

The seismologist has shown us that thousands of earthquakes occur yearly and this indicates a very weak crust; he has also shown by an analysis of the rates and directions of propagations of the seismic wave that the earth is solid throughout.

Isostasy is a static condition of the earth's material, merely a condition of rest which is, of course, disturbed by the shifting of materials horizontally at the surface of the earth or below the crust. The earthquake phenomenon, on the other hand, is a dynamic phenomenon involving the expenditure of energy due to stresses set up by changes in volume or shifting of matter. From the earthquake may be discovered the rate at which changes are taking place in the earth and on the surface, and the magnitude of the forces which are acting.

The seismologist may be able to tell the isostasist the limiting depth to which earthquakes extend. According to the isostatic principle which requires a crust with residual rigidity and a subcrustal material which is plastic to long-continued stresses, no earthquake should occur below the crust. If the seismologist can give accurate data as to the limiting depth of the earthquake epicenter, there will be another line of attack as to the thickness of the outer layer of the earth within which heterogeneous densities may be maintained.

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A consideration of the mechanics or physics of the earth's crust based on the proof of isostasy would lead us to believe that there can be no horizontal movement of crustal material from a low area towards a high one. With the earth's crust in equilibrium, the stress difference would be from the high area toward the low one all the way from the surface down to the lower limit of the crust. At the latter place the stress differences would be zero. If two contiguous portions of the crust in equilibrium were to have a transfer of load at the surface from the high to the low one, and if no movement downward or upward should take place to restore the isostatic equilibrium, then the stress difference between the two blocks would be zero at a depth somewhat above the lower limit of the crust. The perfection of isostatic equilibrium, however, would lead us to believe that the zero stress difference would not be raised very far.

The seismologist can tell us whether at faults the predominant movement is horizontal or vertical at the time of an earthquake. If it is horizontal and of wide extent, then it is possible the conclusion of the isostasist, that there is no great horizontal movement within the crustal material from a low area to a high one, might be found to be erroneous.

It has been found that the topographic feature, which is about thirty miles in diameter and three thousand feet thick, is at least largely compensated. This gives an idea as to the degree to which isostasy obtains.

The isostasist confines himself to analyses of geodetic data and to tests involving the distribution of densities. From this he learns whether the earth has a crust and, if so, whether large portions of it can be maintained in a non-isostatic condition. When he goes beyond this rather narrow field, he is working in the realm of geophysics and geology. It is in these two latter branches of earth sciences that the seismologist has the opportunity to be of great assistance to the isostasist.

U. S. Coast and Geodetic Survey,
Washington, D. C.

NOTE ON THE INFLUENCE OF THE MOON ON EARTHQUAKES

H. F. Reid

Since the time of Perrey much statistical study has been devoted to seeking a relation between the frequency of earthquakes and the position of the moon. Different investigators have arrived at contradictory conclusions; so that the results of all this work have been disappointing. I think we shall see the reason for this if we look at the problem from a dynamical standpoint. The earth is tidally distorted by the moon and stresses must be set up which will add to those growing independently in the earth and influence the time of occurrence of a particular earth-

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quake, and a preliminary estimate indicates that this influence may be important. Yet the influence depends not only upon the position of the moon, but also upon the direction of the strike of the fault where the fracture is about to take place with respect to the azimuth of the moon and on the dip of the fault. Of two faults similarly situated with respect to the moon, but with the downthrow on opposite sides of the fault, one will be advanced and the other retarded. In any large catalogue of earthquakes, faults will be involved striking in various directions, with different dips and with downthrown sides both towards and away from the moon. We conclude, therefore, that although the moon may have a definite effect on any particular fault, the hour-angle for its greatest effect will differ much for different faults, and no hour-angle will be especially predominant when a long list of earthquakes are studied statistically. This is only a preliminary note on a subject still under investigation.

Johns Hopkins University,
Baltimore, Md.

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SECTION OF METEOROLOGY

(Washington, D. C., April 30, 1926)

In the absence from the city of Professor C. F. Marvin, who was scheduled to open the program, the Chairman, C. G. Abbot, by request, presented a report on incidents connected with his recent journeys in Europe, Asia, and Africa having for their purpose the establishment of a station for determining daily values of the solar constant of radiation. Funds for the support of this station have been provided by the National Geographic Society. He announced the selection of a site in Southwest Africa where the meteorological conditions promised to be even more favorable than in Chile.

DISCUSSION OF QUESTIONS INVOLVING INTERNATIONAL COOPERATION

1. "Proposition for greater uniformity in pyrheliometric observations" (H. H. Kimball, U. S. Weather Bureau). An examination of pyrheliometric readings made at nearly one hundred points of observation during the last forty years indicates that greater uniformity of method and careful intercomparison of pyrheliometers is desirable. In a majority of cases the altitude of the Sun at the time of observation is given. Such observations can be summarized in such a way as to be directly comparable, provided the constants of the pyrheliometers permit of reducing all the readings to the same pyrheliometric scale. Intercomparison of the Smithsonian silver disk pyrheliometer, the Marvin silver disk pyrheliometer, and the Angström electrical compensation pyrheliometer make it possible to reduce the readings of these instruments to a common scale, provided, of course, the instruments are all in good condition. In the case of observations taken near noon only, as is the case at some stations, it is not so easy to summarize them in such a way that they are comparable with readings made at other stations; although valuable, they require a great deal of labor to adapt them to many meteorological problems.

2. "Measurements of the ultra-violet of solar radiation" (W. J. Humphreys, U. S. Weather Bureau). Since surprisingly and, as yet unaccounted for, great variations in the ratios of the ultra-violet to the green portions of the solar radiation have been reported, and since the shorter wave-length part of insolation is of great physiological importance to both animals and vegetables, it seems desirable that careful measurements of the ultra-violet be made at all the principal pyrheliometric stations.

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3. "Shall the intensity of solar radiation be expressed in units of heat or power?" (H. H. Kimball, U. S. Weather Bureau). It is now almost the universal practice to record solar-radiation intensities in units of heat, namely, gram-calories per minute per square centimeter. More and more, however, we are coming to think of solar thermal energy. Therefore, the question arises why the intensity should not be expressed in units of energy with which we are familiar.

4. "The correlation of solar-radiation data with terrestrial weather" (A. J. Henry, U. S. Weather Bureau). In view of the probable early completion of arrangements for measures of the constant of solar radiation at one additional station in Africa, it is advisable that organized meterological services throughout the world undertake the correlation of all available measures of solar radiation with terrestrial weather, having due regard for the claims of provisional value that have been advanced with respect to them. While individual research on the problem is not discouraged, it is believed that tests by organized services that are charged with the duty of forecasting the weather hold out greater promise of finality than do those made by individuals.

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SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

(Washington, D. C., April 29, 1926)

RESULTS OF RECENT EXPERIMENTS ON COSMIC RAYS

R. A. MILLIKAN

Abstract.—The paper presented a synopsis of the methods used and results obtained by the author and his associates, I. S. Bowen, R. M. Otis, and G. H. Cameron, in the investigations on high-frequency rays of cosmic origin (1) in sounding balloon observations at extreme altitudes, (2) by mountain-peak and airplane observations, and (3) by measurements in snow-fed lakes at high altitudes.[1]

Discharge rate of an electroscope at altitudes from 5 to 15.5 km.—Four specially designed instruments, each comprising a recording electroscope, thermometer, and barometer and each weighing but 190 gr., were sent up with sounding balloons from Kelly Field, Texas. Three were recovered, and of these two had satisfactory records of their flight, during which they reached altitudes of 11.2 and 15.5 km., respectively. A comparison of the recorded electroscope reading at the 5-km. level during ascent, with the reading at the same level, during descent, shows that the average discharge rate of the electroscope while between the 5-km. level and the 15.5-km. level was about three times its discharge rate at the surface of the earth, and corresponded in this particular instrument to an average rate of production of ions of 46.2 ions per cc. per sec. This is only 25 per cent of the value to be expected from the observations of Hess and of Kolhörster, and constitutes definite proof that there exists no penetrating radiation of cosmic origin having an absorption coefficient as large as 0.57 per meter of water.

Mountain-peak and airplane observations.—The elimination in penetrating ray experiments of temperature and pressure effects is accomplished through new features in the design of Wulf electroscopes, but especially through immediate reduction *in situ* of all deflections to volts. When suitable precautions are taken for eliminating the activity of adjacent rocks, both airplane and mountain-peak observations agree in showing a definite variation of the penetrating radiation with altitude alone. Within the limits of experimental error, all observations are consistent in showing no dependence of the penetrating radiation upon the time of day or upon the position of heavenly bodies. Absorption experiments made on Pikes Peak with lead sheets 4.8 cm. thick furnish evidence for the existence on mountain peaks of copious rays of local origin

[1] *Cf.* R. A. Millikan, Proc. Nat. Acad. Sci., vol. 12, pp. 48-55, January 1926; R. A. Millikan and I. S. Bowen, Phys. Rev., vol. 27, pp. 353-361, April 1926; R. A. Millikan and R. M. Otis, Phys. Rev., vol. 27, pp. 645-658, June 1926; and R. A. Millikan and G. H. Cameron, Phys. Rev., vol. 28, pp. 851-868, November 1926.

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of no greater hardness than that of gamma-rays. If all the rays found on the peak are assumed to be homogeneous, their absorption coefficient is about 3.1 per meter of water, or near that of ordinary gamma-rays. These experiments, however, furnish no definite evidence for the existence of very penetrating rays of cosmic origin. Such rays, if they exist, cannot produce as much as 2 ions per cc. per sec. at sea-level if they have an absorption coefficient not less than 0.25 per meter of water. If cosmic rays exist at all, they must be less intense than this, or else they must be more penetrating than anyone has as yet suggested.

Measurements in snow-fed lakes at high altitudes.—The following synopsis gives the results of observations made in snow-fed lakes at high altitudes: (1) Absorption experiments in Muir Lake (alt. 11,800 feet). The sinking of sealed electroscope No. 3 in Muir Lake showed an ionization decreasing steadily with depth, from 13.3 ions per cc. per sec. at the surface to 3.6 ions at 50 feet below the surface, below which there was no further decrease. The absorption curve of electroscope No. 3 was in excellent agreement with that of No. 1. (2) Absorption experiments in Arrowhead Lake (alt. 5,100 feet). The electroscope readings in Arrowhead Lake correspond uniformly to readings six feet deeper in Muir Lake. This difference is the exact water equivalent of the absorption of the atmosphere between the two elevations. All readings of both electroscopes fit satisfactorily upon a single curve relating ionization to depth beneath the surface of the atmosphere in equivalent meters of water. (3) Rays of cosmic origin. (1) and (2) combined with the failure to detect any systematic diurnal variation in tests of a number of days' duration at high altitudes, constitute new and quite unambiguous evidence for the existence of very hard etherial rays of cosmic origin entering the earth uniformly from all directions. (4) Spectral distribution of cosmic rays. No single absorption coefficient is found to fit the absorption curve, the lower end of which requires a coefficient of 0.18 per meter of water; the upper end a coefficient of 0.30 per meter of water. These coefficients correspond, by Compton's equations, to wave-lengths $\lambda = 0.00038$ A. and $\lambda = 0.00063$ A. These are fifty times the frequencies of ordinary gamma-rays, $\lambda = 0.025$ A., and the former corresponds to an energy of 32,000,000 volts. (5) Number of pairs of ions due to cosmic rays. The observed number of pairs of ions in electroscope No. 1 due to cosmic rays is about 1.3 at sea-level, 2.6 at 1,600 meters, 4.8 at 3,600 meters, 5.9 at 4,300 meters. (6) Stimulated secondary rays. Theoretically, cosmic rays of the foregoing energy should not stimulate ether waves of gamma-ray hardness, but should produce beta-rays capable of penetrating brass walls 5 mm. thick. The observations present evidence of rays of about this hardness, increasing systematically with altitude in rough proportionality to the intensity of the cosmic rays.

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This evidence is not completely convincing because of inability thus far to eliminate the effects of the gamma-rays from the underlying rocks. (7) Origin of cosmic rays. Evidence is presented that these rays do not result from the union of protons with negative electrons, but that they are rather due to nuclear changes of about one-thirtieth the energy corresponding to such union, taking place throughout the depths of the universe.

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IMPROVEMENTS IN MAGNETIC RECORDING INSTRUMENTS TO FIT THEM FOR SPECIAL INVESTIGATIONS

N. H. Heck

The Coast and Geodetic Survey has for a number of years been laboring with the problem of doing the necessary work on its routine publications of observatory results in Terrestrial Magnetism, a problem which has been made more difficult by the assignment of work in seismology to the same Division. It has not, however, overlooked the fact that in order to accomplish this successfully it is necessary to study and improve the instruments. The subject of this symposium is the development of special instruments, and I will not be able to contribute greatly to this part of the subject. However, there have been some fundamental needs which must be met before our standard instruments develop their full capabilities. It is obvious that if a problem can be solved by a slight adaptation of present instruments and methods, the chances of its solution being undertaken are greatly increased. In this respect there have been, I think, a number of substantial contributions.

In 1924 George Hartnell, observer-in-charge of the Cheltenham Magnetic Observatory, Cheltenham, Maryland, prepared a study of the horizontal intensity variometer, which is published as Special Publication No. 89 of the Coast and Geodetic Survey. In this publication he treated the subject in an exhaustive manner. A number of suggestions as to the improvement of instruments were made, and in order to carry these out a small experimental building was erected. This building has proved of the greatest value ever since, and a number of important problems have been worked out there. So far as the Coast and Geodetic Survey is concerned, the study of temperature compensation of the H variometer has been the most important. The method and some of the results are given in the Journal of Terrestrial Magnetism for September, 1925. The method has so much promise that a compensated variometer is now in use in Porto Rico and one is being prepared for use at Cheltenham. The adaptation is simple. A suitable magnet is placed at such a distance that the field at the suspended magnet is one-half that of the earth's field.

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It can be shown theoretically and proved by experiment that in this case there is accurate compensation. There seems to be no good reason why this plan should not be universally adopted. Even if the compensation is not quite perfect, there is a great advantage in having a small temperature coefficient. With temperature compensation, the H curve can be interpreted in absolute values simply by applying the scale value and the base line. This in turn makes possible a method of direct scaling of the magnetograms. This is now being done at Cheltenham, and it is hoped that eventually a single scaling at the observatories will suffice, except for a slight final revision. The only objection to this plan is that the scaling must be delayed several months in order that the scale value and base lines may be worked out.

The next important line of attack, which has a bearing both on routine and in investigations, is the improvement of instruments to obtain scale values and base lines which will not be subject to sudden changes for instrumental reasons. In view of the accuracy of the measurements this may not be entirely obtainable; but all those who are directing magnetic observatories know that there is a great need for a vertical intensity variometer which will give a better performance in these respects. The Coast and Geodetic Survey and the Carnegie Institution of Washington are both deeply concerned with this problem and are bending their efforts to a solution. It is hoped that in a year from now a more satisfactory instrument will be either in use or in the process of development.

Another important point is the recording apparatus. It is well known that difficulties are involved in securing uniform rotation of a recording drum and most of the early attempts have been in fact very crude as compared with present standards. It is now possible to secure accuracy according to the needs even to one ten-thousandth of a second in time. The difficulties naturally increase with the requirements of accuracy. In recording the magnetic records there are special difficulties, due to the fact that the recording apparatus must be practically non-magnetic. It seems, however, that the requirement that it be possible to scale times from the records which are correct within a few seconds is not unattainable. Such accuracy is called for in such investigations as that of the propagation of magnetic storms. Ordinarily such accuracy is not required. In this connection I may state that electrical methods may be used in a magnetic observatory if special precautions are taken. This will probably be brought out more clearly by Mr. Fleming.

The fact that the Coast and Geodetic Survey is carrying on at the same time investigations of magnetic and of seismological problems, and of acoustic problems as well, is promising of results, because all of these problems have a great deal in common. The solution of a problem in any one of these subjects may have a direct bearing on a solution in another.

Another very promising feature in the present situation is that the

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Coast and Geodetic Survey and the Department of Terrestrial Magnetism are working together in solving such problems. Each is making an important contribution without overlapping the activity of the other. Such a spirit is more promising for the future than the actual state of progress at the present time.

In the improvement of optical systems of our magnetic instruments the Navy Department has been of great assistance.

In conclusion I wish to express my opinion that instruments for special investigation should hereafter have the qualities of compensation for temperature, reasonable constancy of base lines and scale values, uniform rotation of recording drums, and good optical systems. The question of whether special apparatus should be developed, or whether we should adapt the present instruments modified as indicated, is then one which should be decided in accordance with the demands of the special problem.

U. S. Coast and Geodetic Survey,
Washington, D. C.

IMPROVEMENTS IN MAGNETOGRAPHS AND VARIOMETERS FOR OBSERVATORY AND FIELD USE

J. A. Fleming

An outstanding need in recording devices for continuous registration of the magnetic elements is better time control. At present the Eschenhagen magnetograph is the one most generally used at observatories. It depends for time control upon short breaks each hour in the base-line produced by a cam and lever actuating a shutter to cut off, for from one to two minutes, the beam of light making the base-line. With such a device, usually operated by the same clock as that driving the rotating drum on which the photographic sheet is placed, parallax of the moving-mirror reflected beam as referred to the fixed-mirror reflected beam may be a serious matter calling for correction; this may arise from lack of parallelism of the horizontal axis of the condensing cylindrical lens in the recorder and of the axis of rotation of the recording cylinder, lack of appropriate adjustment of the mirror systems particularly as regards verticality when swinging freely, etc. The adjustment, so far as the first is concerned, is comparatively easy, but not so as regards the second. Since the time-scale usually employed is 20 millimeters to the hour or one-third millimeter to one minute of time, the error of parallax may become an important consideration, the more so as it may not be constant with varying ordinate. A longer time-scale might help, but economically this is not feasible in view of the greater expense necessitated for paper, for attendance, and for reduction.

Of late, a great deal of attention is being given the study of times of beginning of magnetic storms of various types, chief among these being

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those usually designated "sudden commencements." Examination of records of such storms, for example, that of November 1, 1924, indicates characteristic features common to all of the observatories, but some of the details such as impulse at the beginning and character of first maximum disturbance following the sudden commencement show wide variation. Any question as to compilation of times of beginning is thus subject to two uncertainties, (*a*) as to the definite marking of the particular impulse starting the sudden commencement and (*b*) as to the exact time of this beginning, once careful study has indicated the same point of storm reference. We may hope to eliminate the first by a careful study of the original records, or, preferably, enlargements of them; but time control must be improved and methods developed making possible a precision of scaling for time comparable with any uncertainty concerned in the period or inertia of the moving system. Thus for such records an accuracy of one-fourth minute of time may be considered as a reasonable requirement; that is, the determination of a point on the time-scale to about 0.1 millimeter.

Irregularities of clock performance or non-uniform shrinkage in the photographic paper upon development, therefore, must be controlled as well as the adjustments referred to above. Obviously time-lines of satisfactory intensity once each hour, extending across the width of the record and made entirely independently of the driving clock, for example, by an electric time-device, offer a solution, provided the relation with the time-element of the recorded curve to these time-lines may be fixed. To do this, calls for some device by which exact times may be recorded at intervals by means of the moving mirror of the variometer. This may be accomplished by using a second slit at the source of illumination which may be automatically opened at fixed times and thus record for a brief exposure spots to one side of the recorded curve and of the recorded base-line. A second method, and one which has the advantage of giving at the same time data for scale-value determinations, may be effected by centering Helmholtz-Gaugain coils of suitable dimensions and orientations about each variometer and then passing, for short intervals at fixed times, first a small positive and then a like negative current through the coils, thus producing deflections on either side of the recorded curve. Exact measures of the photographic record then provide quite sufficient control on the relation of the time-lines to the time-scale of the curve. Messrs. Parkinson, Huff, and Goldsmith, of the Department of Terrestrial Magnetism, have been carrying on this development work in the experimental building at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey, where they have the hearty cooperation of Mr. G. Hartnell, Observer-in-Charge.

The results of earlier and recent investigations of possible correlations between the magnetic and electric activities of the Earth and solar ac-

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tivity, particularly those of Bauer, Peters, Chree, Rodés, and others, emphasize the desirability of having at solar observatories some simple recording device for one or more of the magnetic elements, so arranged that the magnetic state of the Earth may be noted visually at any time and from time to time it may be determined whether any natural magnetic disturbance exists, thus permitting an intensive program of solar observations during such times. The importance of this subject has been emphasized by a resolution of the committee appointed by the International Research Council for the study of solar and terrestrial relationships (Dr. S. Chapman, Chairman). This resolution, favorably acted upon at the Brussels meeting, last July, reads as follows:

"The Committee recommends that solar observatories should make additional observations on the sun, as nearly continuous as possible, at or about the times when magnetic storms are in progress, or when they may be expected in accordance with the 27-day recurrence-tendency. This would necessitate the organization of a service for the supply of information to solar observatories as to magnetic storms, prospective or in progress. The Committee recommends that Dr. L. A. Bauer, the Secretary of the Section of Terrestrial Magnetism and Electricity of the International Union for Geodesy and Geophysics, be asked to formulate a scheme for this service."

Acting on this suggestion, the Mount Wilson Observatory and the Department of Terrestrial Magnetism hope to cooperate in carrying out such suggestions and plans as may be developed. Meanwhile, consideration is being given the application of the Eschenhagen type of variometer by so mounting it that, while recording photographically, the introduction of a prism or mirror in the course of the recording light-beam may give a visual projection on a ground-glass screen. To determine whether magnetic conditions are normal or disturbed, use can be made of the previous month's mean curve for normal days as recorded by the instrument; a simple clock-operated device can be made to show on the ground-glass screen the portion of the curve corresponding to any time of day, thus always affording visual means of estimating the general character of the Earth's magnetic activity. The first experimental work might be confined to the horizontal-intensity variometer, suitable control magnets being mounted for temperature compensation following the method originally developed at Potsdam and more recently applied by Mr. Hartnell.

It has been suggested that the declination variometer might be as well suited as the horizontal-intensity variometer, if suitable control magnets were mounted to greatly increase the sensitivity. In general, however, it appears that the horizontal intensity may be a better gauge of magnetic activity. The investigations by Bauer and Peters indicate that perhaps in such work the vertical intensity may be more suited for the study of possible correlations. The present type of vertical-intensity variometer

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has certain mechanical defects inherent to pivot suspensions which must be eliminated to obtain greater constancy of performance. As Commander Heck has stated, the Coast and Geodetic Survey and the Department of Terrestrial Magnetism are cooperating in improving the design of the vertical-intensity instrument, the Department approaching the problem through electrical methods.

Recently, increasing emphasis has been centered on the study of the change with geographic position of the diurnal variations of the magnetic elements, and the observers of the Department of Terrestrial Magnetism have been obtaining continuous observations during the daylight hours at stations in all parts of the world, using the magnetometer attachment on one day to obtain such variations in declination and horizontal intensity simultaneously, and the inductor attachment on a second day to obtain such variations in inclination. This application of the inductor in field observation of variations gives quite satisfactory results directly, without the necessity of corrections on account of temperature changes when using intensity variometers.

That diurnal and secular variations may have relationships depending upon locally disturbed conditions, has indicated the need of instruments that may be used for rapid surveys of locally disturbed areas. Such instruments have application not only in obtaining data of this kind but also in economic geology. Thus, in the case of certain conditions of magnetic anomaly or in the event of the intrusion of nonmagnetic material, for example, a salt dome, in a formation of otherwise uniform magnetic character, such instruments afford a possible means of determining geological conditions and of making mineral surveys. Instruments used in such work include the universal magnetic variometer and magnetic field-balance of Schmidt's design, the Rühstrat horizontal-intensity variometer, and the earth inductor and compass-variometer of the Carnegie Institution of Washington.

The universal magnetic variometer as designed by Schmidt is used mainly for the determination of the variations of declination and horizontal intensity; the compass needle is suspended on a thin wire and the readings are effected with a telescope, mirror, and scale, the sighting being done with a telescope. The deflecting magnets are used to compensate the horizontal component of the Earth's field by moving them around and along the vertical axis of the instrument. A type of this variometer is also constructed for vertical intensity, this field-balance consisting primarily of a light magnetic needle swinging in a vertical plane attached to a thread kept horizontal by tension, readings being made by telescope, mirror, and scale.

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The Rühstrat horizontal variometer utilizes needles with double-pivoted suspensions. Its sensitivity is altered by the slow-motion adjustment of an auxiliary bar-magnet.

For regions where the inclination is 70° or less, the C. I. W. earth inductor in connection with its field galvanometer is well adapted in the rapid surveys of regions of magnetic anomaly or of suspected mineral deposits. It is possible to determine in a few minutes of time at any station the value of magnetic inclination with an accuracy of one-quarter minute. In one such survey, where the value of the declination was about 61° and extreme ranges in vertical intensity and horizontal-intensity values were 400 and 280 gammas (one gamma = 0.00001 C. G. S. unit), the corresponding difference in inclination deduced for the two points of maximum and minimum values is 35 minutes of arc. Thus the earth inductor would have served excellently for the rapid delineation of the magnetic disturbances over this area, particularly in conjunction with an instrument capable of like rapid and accurate observation in horizontal intensity.

Compass-variometers designed by the Department of Terrestrial Magnetism suitable for the investigation of local magnetic disturbances, the detection of effects caused by hidden magnetic materials, and for register ing intensity variations with high precision, involve the following principal. Two magnets of equal magnetic intensity are suspended independently one above the other and so mounted that the distance between them may be varied to obtain a fixed horizontal deflection-angle for a particular, but not necessarily known, intensity of field. The sensitivity of such an instrument, that is, the change in the magnetic field causing a divergence of 1° from the fixed angle between the magnetic axes of the magnets, depends upon the magnitude of the fixed angle. Thus the value of this angle may be adopted according to the requirements of the particular problem in hand. The magnets finally adopted as a result of the experimental work were the disk type of very thin magnet steel.

In the model best suited for land work the magnets are damped electromagnetically by copper dampers; liquid damping has been used in other models, particularly those intended for use at sea. The magnets for the instruments constructed are mounted either on pivots with agate jewels, the centers of gravity being some distance below the point of support, or in double-pivoted suspensions. It is planned also to use quartz-fiber suspensions to reduce friction of pivot supports. The main features of the instrument may be summarized as follows: (*a*) Maintenance of a fixed relation between the axes of the magnets or magnet-systems making possible, in connection with (*b*), the construction of a short-period detecting instrument suitable for rapid surveys of high precision and investigations of magnetically disturbed regions; for example, magnetic

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fields in buildings, magnetic fields about iron ships, regions of local disturbance in the Earth's magnetic field; (*b*) the arrangement for readily changing the distance between the magnet-systems to obtain the position of equilibrium of the magnets on any course, thus adjusting mechanically when used on board ship for variations in the magnetic field caused by the ship's magnetism; (*c*) the disk type of magnet and the axle-mounting make possible accurate balancing of magnets or magnet-systems, thereby decreasing troublesome dynamic effects on board ship; (*d*) the arrangements of single containers making automatic provision for all expansion and contraction of the damping liquid without setting up disturbing currents; and (*e*) the optical arrangements for eliminating parallax, thus reducing uncertainties and inaccuracies of observation.

For investigations involving detailed delineation of magnetically disturbed areas and where many determinations of reasonable accuracy are required, the earth inductor and compass-variometer greatly expedite observation and make feasible detailed surveys that would be impracticable, if not impossible, with magnetic instruments of the ordinary type. The compass-variometer and the field type of inductor thus seem particularly suited for work of this character.

Washington, D. C.
Department of Terrestrial Magnetism,
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IMPROVED EQUIPMENT FOR MEASURING EARTH-CURRENT POTENTIALS AND EARTH-RESISTIVITY

O. H. Gish

Although other methods have been proposed for determining the density and direction of the natural electric currents which flow in the Earth's crust, those which have thus far been put into use require two classes of measurements, namely, measurements of the differences of potential between points in the Earth taken in such a way as to yield the potential gradient, and measurements constituting a survey of earth-resistivity in the region where the potential measurements are made.

Earth-current observations heretofore have been incomplete, in that the resistivity measurements have not been undertaken. A method has been developed and is now in use at the Watheroo Magnetic Observatory of the Carnegie Institution of Washington by which it is possible to obtain a fair knowledge of the distribution of earth-resistivity, both laterally and with depth. From these two types of measurements, the density and direction of the earth-currents can be determined. The method of measuring potentials which has been in operation at the Watheroo Observatory for over two years, although modeled upon schemes previously used

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elsewhere, contains some novel features which seem to be genuine improvements.

POTENTIAL MEASUREMENTS[1]

In the diagram shown, the positions where contact to earth is made were indicated by points lettered O, P, Q, M, and N. O, P, and Q are spaced at intervals of one mile on a north-south line, while O, M, and N have the same spacing on an east-west line. The character of these contacts is a matter of great importance, since electrochemical E. M. F.'s of magnitudes as great or greater than the potential differences which it is sought to measure, are almost certain to occur. At present there is little, if any, hope of either eliminating these or making them negligible, but by using suitable material and with proper installation of these electrodes the electrochemical E. M. F.'s will generally remain constant enough, so that the more rapid variations in the earth-currents may be satisfactorily measured. It is, however, desirable to have some criterion by which it is possible to determine whether the desired constancy exists. A criterion is obtained in the present installation by using such an arrangement of electrodes that for each component three separate records are obtained which are independent except for effects arising at electrode O, the common point of reference. These would introduce spurious effects of the same magnitude in all the records, whereas, variations in the electrochemical E. M. F. of any other electrode will enter only in a single record. This sort of test has already shown its worth, not only in appraising the records obtained, but also in locating the source and ascertaining approximately the cause of the disturbance. Furthermore, a nonuniformity of the field will likely manifest itself with such an arrangement.

Lead was found from tests in the laboratory to give smaller and more steady contact E. M. F.'s than any other material examined, and, furthermore, the current flowing while setting the potentiometer produced relatively little polarization in electrodes of this material. Lead was accordingly selected for use as electrodes. Another feature is the use of both overhead and underground connecting lines. Two independent electrodes are installed both at M and at P. One of these connects with the recording instrument by an overhead conductor, the other by an underground cable consisting of lead-sheathed copper conductor placed in a bituminous conduit. No difference has been observed between the records obtained from the two types of lines, except on the occasion of a few thunderstorms, when all the overhead lines showed marked disturbances, while the

[1] See, also, Gish, O. H., "General description of the earth-current measuring system at the Watheroo Magnetic Observatory," Terr. Mag., vol. 28, pp. 89-108, 1923.

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underground lines were unaffected. The earth-current potentials recorded during magnetic storms have always shown pronounced and consistent variations for the two types of lines. This fact, if borne out by further observations, will be of great importance in the interpretation of earth-current records at such times.

The measuring instrument used at Watheroo, a recording potentiometer, is a distinct departure from previous practice in earth-current measurements. Heretofore some type of galvanometer has been used, having in some cases a rather low effective resistance. Records obtained with galvanometers may be affected by variations in the circuit resistance, especially that part contributed by the electrodes, interaction between the several circuits, and distortion of the electric field and polarization of the electrodes resulting from the current flowing through the galvanometer. When using a potentiometer, or null method, these difficulties are largely obviated; variations can then only affect the precision of a setting, and that but slightly for ordinary changes at the time of balance no current traverses the electrodes and, consequently, no distortion of field results from this cause; no two of the circuits through the electrodes are closed simultaneously; hence, interaction is avoided, polarization effects in a single setting are minimized by the use of the null method, and, furthermore, the order of recording may be so arranged that for most circuits the residual polarization will enter successively in opposite sense and thus be largely eliminated in an hourly mean. A feature of this method which may at first thought seem a disadvantage is the intermittent character of the record. However, changes having a duration of ten minutes or more may be followed quite satisfactorily, while to follow changes of much shorter period a more open time-scale and a less sluggish instrument than is suitable for general recording, is necessary.

This instrument, a Leeds and Northrup 12-point recorder, with specially designed circuits, prints a point on the record at intervals of 55 seconds. The width of the record sheet is 25 cm., which will accommodate a range in the measured potential differences of 80 millivolts when employing the highest sensitivity. In the instrument as now modified the paper moves at the rate of 3.8 cm. per hour. The calibration of the instrument is sufficiently constant and uniform that the potential differences may be read directly from the ruled paper with an uncertainty no greater than ± 0.2 millivolts. At 10-minute intervals the potentiometer circuit is automatically balanced against a standard cell. By suitable connections between two columns of binding posts on a panel to the left of the instrument, any one of twelve different base-lines may be used with each of the twelve possible electrode connections, thus making possible in general the use of higher sensitivities.

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METHOD OF MEASURING EARTH-RESISTIVITY[1]

The method used for obtaining the resistivity of the Earth in the region where the earth-current potentials are recorded is an adaptation of the scheme first suggested by Wenner[2] and modified by McCollum[3] for use in electrolysis surveys. Four terminals to earth, or electrodes, are placed at equal intervals along a straight line. A battery and a meter are connected between the two extreme terminals, so that a measured current may be passed through the earth between these points. The resulting difference of potential between the intermediate points is measured with a potentiometer. From the current (I) and the potential difference (V) thus observed, together with the length of interval (a), the resistivity (ρ) may be determined from the equation

$$\rho = 2\pi a V/I$$

provided the distance a is large enough so that the electrodes which form the contact to earth may be considered as points at the Earth's surface. The value of resistivity thus found must, however, in general, be considered an average in which that of the earth near the line of terminals is the more heavily weighted, while the weighting diminishes with distance from this line until at a depth, or lateral distance, equal to the distance between adjacent terminals the weights have become so small that all the earth beyond this contributes comparatively little to the total effect. Thus the body of earth involved in a single determination has linear dimensions of the same order as the interval between terminals. By increasing this interval, greater depths of earth may be included, so that from a series of such measurements a fairly satisfactory knowledge of the variation of resistivity with depth can be obtained, provided the series are repeated at positions suitably distributed over the region.

The measuring circuits with instruments and the arrangement of the contact points, or electrodes, were shown diagrammatically. The contact to earth at four points (C_1, P_1, P_2, and C_2) is made by means of steel rods (5/8 inch diameter, 2 feet long) inserted generally to a depth of one foot, but in no case should the depth exceed five per cent of the distance between electrodes. The resistance of the measuring circuits arises largely at the contact with earth. This, when too large, may be reduced by inserting several electrodes at each "contact point," provided the linear dimensions of the area over which they are distributed are small compared with the distance between contact points.

[1] See, also, Gish, O. H., and W. J. Rooney, "Measurement of resistivity of large masses of undisturbed earth," Terr. Mag., vol. 30, pp. 161-188, 1925.

[2] Bull. U. S. Bur. Standards, vol. 12, pp. 469-478, 1916.

[3] Measurement of earth-currents, Elec. Ry. J., Nov. 5, 1921.

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The potentiometer and milliammeter are mounted as one unit. The former has two ranges (0 to 100, and 0 to 1,000 millivolts), and the latter has five ranges (0 to 50, 0 to 200, 0 to 500, 0 to 1,000, and 0 to 2,000 milliamperes). In order to minimize polarization of the electrodes and to eliminate the potential difference arising from currents present in the Earth from other sources, a double commutator of the type used by McCollum[3] is inserted in the lines between the meters and the electrodes. One section of this commutator reverses the E. M. F. applied across the extreme electrodes; with the other the potential difference between the intermediate electrodes is rectified, so that this may be measured with the direct-current potentiometer. The commutator is mounted in a case along with three radio "B" batteries which provide a total E. M. F. of 135 volts, which is available in various subdivisions.

Numerous preliminary measurements in the vicinity of Washington, D. C., give assurance that with this method and equipment a fairly satisfactory knowledge of the distribution of resistivity, not only laterally, but also with depth, can be obtained. Thus, for example, wholly from measurements over a filled ravine and other surface observations, it was possible to construct the original profile with good approximation, as was later verified from engineer's working plans. Measurements from floats over the Tidal Basin, Washington, D. C., gave for water, by this method, values which agreed within a few per cent with standard laboratory measurements upon samples which were collected during the field operations. The depth of the water could be correctly inferred from the resistivity measurements and apparently also the depth of silt and depth to solid structure beneath this.

The extreme conditions encountered by Mr. W. J. Rooney, who during the latter part of 1925 and in 1926 has been making a survey by this method of the resistivity at the Watheroo Magnetic Observatory of the Carnegie Institution of Washington in Western Australia, brought forth the need of some improvements in the design of the commutator. A new commutator was designed by the writer, with the able assistance of Mr. C. Huff, who also supervised the construction. The current commutating part was designed to transmit 5 amperes at 1,000 volts. Ruggedness and ready portability were requirements, as well as more than ordinary mechanical precision, in order to insure good characteristics in the commutation. The commutator for the high potential circuit, as well as an automatic switch, operates in a bath of switch oil. The former is of the cylinder type, in which marble is used for insulation. Considerable care was also required to obviate serious leaks from the high potential circuits to the potentiometer circuits. Field tests under extreme conditions have not as yet been made, but under moderate conditions and when trans-

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mitting 2 amperes at 1,000 volts the expectations of the designer were fulfilled.

When the intermediate terminals are situated in soils differing much in constitution, a considerable difference in contact potential may exist between them, and as a result the galvanometer used with the potentiometer is set in more or less violent vibration. Under these circumstances, the precision in the potential measurement may be considerably lowered. This difficulty has been recently obviated under extreme conditions by placing a 20-microfarad condenser in one of the lines which connects with an intermediate electrode.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

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SECTION OF OCEANOGRAPHY

(Washington, D. C., April 29, 1926)

OCEANOGRAPHIC INVESTIGATIONS IN THE UNITED STATES WEST OF MISSISSIPPI RIVER, IN ILLINOIS, AND IN THE HAWAIIAN AND PHILIPPINE ISLANDS

T. WAYLAND VAUGHAN

INTRODUCTION

As soon as practicable after the meeting of the Section of Oceanography in April, 1925, I sent to all institutions and individuals whom I knew or supposed to be interested in oceanography, within the area indicated by the above title, copies of the questionnaires prepared by the Section of Oceanography of the International Geophysical Union and a statement as follows:

Biologists.—The names of those biologists who are studying organisms in their relations to the sea should be included, for instance, students of marine ecology, students of the physiology of marine organisms when the investigations are of the relation of the organisms to the medium in which they live, and students of geographical distribution. The names of those conducting purely morphological or systematic investigations of organisms without reference to marine conditions should not be included.

Geologists.—The names of those geologists who are engaged in the study of the form, origin, and history of the ocean basins, submarine earthquakes and volcanoes, and those who are studying marine processes as a basis for interpreting geological phenomena should be included.

Physicists and chemists.—The names of those investigators who devote particular attention to the physical properties of sea water, oceanic circulation, and associated phenomena, and those chemists who conduct investigations of the chemical properties of sea water and of chemical reactions which take place in sea water should be included.

The experience in getting replies was about as usual; some persons were prompt and furnished the information requested, others supplied meager information, some were dilatory, and some did not answer the requests for data. I undertook to fill out the blanks for a number of those from whom no replies were received. The data for this report are incomplete, but still they probably constitute an adequate basis for a very nearly accurate account of oceanographic activities in the western part of our country and its dependencies.

COAST AND GEODETIC SURVEY

A summary report of the work of the Coast and Geodetic Survey is included in the report of the Committee on Submarine Configuration and Oceanic Circulation of the Division of Geology and Geography. Field

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work has been prosecuted by the *Pioneer* during the past year in Alaskan waters across the Gulf of Alaska between Shumagin Islands and Vancouver Island, and off the coast of southern California; by the *Guide* in Oregon and southern Californian waters; and by the *Discoverer* in Hawaiian waters. Many depths were determined by means of the sonic depth finder; and the radio-acoustic method of determining position at sea was further developed. Records of sea temperatures, with some serial vertical sections, and of meteorological conditions and collections of water, plankton, and bottom samples were made for the Scripps Institution of Oceanography.

Important Coast Survey work was also prosecuted in the Philippine Islands.

THE NAVY

An account of the oceanographic work of the Navy is included in the committee report above mentioned. During its cruise to Australia and return, the fleet did a very large amount of oceanographic work. It made records of meteorological conditions and surface temperature and it collected water and plankton surface samples for the Scripps Institution of Oceanography. It also made about 1,000 depth-soundings by the sonic method. The naval transports operating between Seattle and Panama are assisting the Scripps Institution in its investigations by supplying records of meteorological conditions and of the surface temperatures of the waters and by collecting surface samples of water.

MARINE LABORATORIES AND THEIR WORK

California.

Laguna. The marine biological station of Pomona College—biological investigations.

La Jolla. The Scripps Institution of Oceanography of the University of California—all branches of oceanography.

Pacific Grove. Hopkins Marine Laboratory of Stanford University—biological investigations, including some biochemistry and biophysics.

San Pedro. Fisheries Laboratory of the California Fish and Game Commission—problems of fisheries but no general oceanographic work.

Venice. Biological station of the University of Southern California—biological work, including biological surveys.

Washington.

Friday Harbor. Puget Sound Biological Station of the University of Washington—biological investigations.

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Hawaiian Islands.

Honolulu. Marine Biological Laboratory of the University of Hawaii—biological researches.

This short list makes it obvious that there is in the territory of the United States bordering, or lying within, the Pacific, only one institution at which the ocean is studied in any comprehensive way.

INVESTIGATIONS IN THE DIFFERENT BRANCHES OF OCEANOGRAPHY

Submarine configuration, seismology, volcanology.—Although there is deep interest in the geological departments of several universities in these subjects, viz., California Institute of Technology, University of California, Stanford University, University of Oregon in the Pacific Coast states, and in other universities in the interior of the country, the Scripps Institution of Oceanography is the only institution with a marine laboratory which is cooperating in such investigations. Important work is done at the Volcano Observatory at Kilauea on the Island of Hawaii, and in the Philippines at the Philippine Weather Bureau. That there is much activity in this field is shown by the Bulletin of the Seismological Society of America; but it is scarcely enough. In this connection the names of the following should be mentioned: Dickerson, Jaggar, Lawson, Louderback, McEwen, Masó, Vaughan, Wentworth, Willis, and Woods.

Marine sediments and sedimentary processes.—A rather full account of recent publications, reports completed but not yet published, and investigations in progress, is included in the Report of the Committee on Sedimentation, Division of Geology and Geography, National Research Council. Such researches are prosecuted in the geological departments of the Universities of California, Stanford, Illinois, and Iowa, and in connection with the expeditions under the auspices of the Bishop Museum of Honolulu. Other investigations of significance to students of sedimentary processes are those on bacteria, diatoms, and the deposition of $CaCo_3$ by algae, by Becking; the growth and relations of corals to environment, by Edmondson; $CaCO_3$ deposition by organisms and the deposition of Ca and Mg from seawater, by Irving; marine bacteria and the chemical composition of Corallinaceae, by Lipman; and the rôle of calcareous algae as rock-builders, by Setchell. The only marine laboratories at which such investigations are conducted are those of the University of Hawaii, Scripps Institution, and Stanford University at its Hopkins Marine Laboratory at Pacific Grove. Of these institutions maintaining a marine laboratory, investigations of marine sediments form a definite part of the program of only the Scripps Institution. Those interested in such investigations are Becking, Blackwelder, Ed-

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mondson, Faustino, Feliciano, Irving, Ladd, Lipman, Louderback, Setchell, Trowbridge, Vaughan, and Wentworth.

Physical and chemical oceanography.—Only at the Scripps Institution are investigations in these fields prosecuted according to a definite and comprehensive program. Since accounts of these researches have been given elsewhere, they will be merely mentioned here. McEwen, Moberg, and Chambers are the principal workers. Becking and Irving are conducting, at the Hopkins Marine Laboratory, researches of importance to chemical oceanography; and the studies of Thos. G. Thompson on the diffusion of seawater in Lake Washington and the effect of land drainage on Puget Sound deserve mention.

Biological oceanography.—Reference to the list of marine laboratories and to the kind of work done at them, shows that more attention is paid to the organisms found in the sea than to the sea itself or to any other feature of the sea, and it may be noted that usually the sea is not adequately studied for an understanding of the medium in which the organisms live.

Quantitative and ecological studies of marine plankton are conducted only at the Scripps Institution, where Allen, Esterly, Moberg, Dorman, and Sleggs are engaged on such work. The mathematical basis for the treatment of the statistical data has been developed by McEwen. Kincaid and Rustia report interest in plankton. Kofoid is known to be active in the study of marine proto-zoology.

Researches in physiology and ecology are carried on at most of the laboratories. The work of Becking and Irving at Pacific Grove merits special mention for the consideration these men are paying to the chemistry of seawater as the medium in which the organisms live and to chemical changes resulting from the activities of the organisms. The investigations of Moberg at the Scripps Institution are gradually yielding a large volume of accurate information on the chemical features of the seawater as related to organisms. Others engaged in physiological and ecological investigations are Allen, Child, Fisher, Gardner, Hinricks, Hilton, Hymans, Myrtle Johnson, F. R. and R. S. Lillie, S. P. Miller, Setchell, Shelford, Tilden, Ulrey, and Weese.

Among specialists on particular groups of organisms are Kofoid on protozoa; Hanna on marine micro-organisms; Nutting on coelenterates; Edmonson, Faustino, Griffin, and Vaughan on corals; Fisher on asteroidea; Barnhart, Evermann, Jordan, Snyder, Sumner, and others on fishes; Evermann and Hanna on marine mammals. There are other group specialists from whom no reports were received, but there is question as to whether the work should be considered oceanographic. The work of Merrill on the geographic distribution of plants in Malaysia and

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Polynesia is both profound and wide in its scope and is firmly tied into suboceanic topography and geological history. Hoagland's studies of kelp may be classified as chemical or biological. He has paid special attention to the selective absorption of ions.

Investigations of fisheries problems claim the attention of Cobb, Crawford, Herre, Kincaid (ostreiculture), McMillin (razor clam), Montalban, Nightingale, N. B. and W. L. Scofield, Selle, Snyder, W. F. Thompson, and H. B. Ward. Ward is studying the diseases of salmon, and Sleggs has completed a paper on cestodes and trematodes of fishes of southern California. More work on fisheries has been done than is here catalogued. Several papers of importance have been published in the bulletins of the California Fish and Game Commission and by the Department of Fisheries of the State of Washington.

CONCLUSION

This brief review reveals the lamentably small attention being paid in the western part of the United States to the study of the ocean. Knowledge of the depths of the sea is derived through the work of the Coast and Geodetic Survey and the Navy. Meteorological conditions over the sea are reported to the Weather Bureau, and records of surface temperatures are derived from a number of sources; but it appears that only the Scripps Institution is making any use of such data. Accurate work on salinity is done only at the Scripps Institution, which is undertaking the calculation of oceanic circulation, largely from data and water samples contributed by the Coast and Geodetic Survey. Vertical sections of the seawater are made only by the Coast and Geodetic Survey and the Scripps Institution. We should be thankful for all the existing instrumentalities for studying the sea; but not enough is being done to understand the great phenomena exhibited by it and to obtain knowledge of its circulation, of the interrelation of the oceans and the climate of the lands, of a medium in which geological processes of great moment are taking place, and of the medium which contains the greater part of the life on earth. Much of the work on marine organisms is scarcely marine biology, for the organisms are not considered in their relations to the sea—relations which cannot be considered until the sea is known. The quantitative study of the small organisms in the sea is confined to one place. Fishes are investigated without due consideration of the physical and chemical features of the medium in which they live and without reference to their fundamental food supply. What can be done to improve these conditions?

Scripps Institution of Oceanography.
La Jolla, California.

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PHASES OF THE WORK OF THE PAST YEAR BASED ON THE NEW ENGLAND STATES, WHICH CONCERN THE SECTION OF OCEANOGRAPHY

H. B. BIGELOW

Abstract.—A report on the continuance of the joint work on the north Atlantic by the Museum of Comparative Zoology of Harvard University and by the Bureau of Fisheries. A report was also made of the Bureau of Fisheries having received from the Navy a new vessel, to be renamed *Albatross II*, for this work.

Harvard University,
Cambridge, Massachusetts.

OCEANOGRAPHIC WORK ORIGINATING IN THE NEW YORK REGION DURING 1925-1926

ROBERT C. MURPHY

Expeditions which have included oceanographic, or related field, work in their schedules during the last year are as follows:

Cruise of Mr. Harry Payne Bingham's yacht *Pawnee.*

Cruise of Mr. William K. Vanderbilt's yacht *Ara.*

Cruise of the steamship *Arcturus,* under the auspices of the New York Zoological Society.

Investigations by the writer along the west coast of South America, under the auspices of the American Museum of Natural History.

THE VOYAGES OF THE PAWNEE AND THE ARA

In February, 1926, Mr. Bingham's yacht, which is equipped with a sounding machine, nets and dredges of several types, and other oceanographic apparatus, sailed from New York for three or more months' work in Pacific waters between Panama and the head of the Gulf of California. Mr. L. L. Mowbray, of the New York Aquarium, accompanied the vessel as technical assistant. No details have been learned concerning the specific objects of the expedition, but it is known that the collection of fishes is contemplated.

During February and March, 1926, Mr. William K. Vanderbilt's yacht *Ara* visited Old Providence Island, Cocos Island and the Galápagos. Press reports, of March 31 and subsequent dates, refer to soundings and tow-net hauls to depths of "half a mile" in both the Atlantic and the Pacific, but no precise information is as yet forthcoming.

ARCTURUS EXPEDITION

The voyage of the *Arcturus* is officially designated as the "Ninth Expedition of the Department of Tropical Research, New York Zoological

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Society." The *Arcturus,* originally a cargo-carrying steamer of 2,478 gross tonnage, was reconditioned and well equipped for oceanographic work by friends and patrons of the Society. Under the direction of Mr. William Beebe, the vessel was on cruise from February 11 to July 30, 1926. The regions visited comprise parts of the subtropical North Atlantic, and Pacific waters lying between Panama, Cocos Island and the Galápagos Archipelago. The staff of the vessel was as follows:

William Beebe, Director.
W. K. Gregory, Associate in Vertebrates.
L. Segal, Associate in Special Problems.
C. J. Fish. Associate in Diatoms and Crustacea.
John Tee-Van, General Assistant.
E. B. Schoedsack, Assistant in Cinematography.
William H. Merriam, Assistant in Field Work.
Isabel Cooper, Scientific Artist.
Ruth Rose, Historian and Technicist.
Elizabeth Trotter, Assistant in Ichthyology.
M. D. Fish, Assistant in Larval Fish Distribution.
Helen Tee-Van, Assistant Artist.
Dwight Franklin, Assistant in Fish Preparation.
Jay F. W. Pearson, Assistant in Macroplankton.
Serge Chetyrkin, Preparateur.
D. W. Cady, Surgeon.

Accounts of the cruise from the pen of Mr. Beebe were published currently in the *New York Times.* The only reports of a less subjective nature which have as yet appeared are a general record in the *Zoological Society Bulletin* (vol. 28, no. 4, pp. 79-116; no. 5, pp. 119-129, 1925), and a brief note by Mr. Beebe in *Science* (A Note on the Humboldt Current and the Sargasso Sea, *Science,* vol. 63, pp. 91, 92, 1926). Dr. Charles J. Fish, who was assigned to the expedition by the Bureau of Fisheries, has reported in manuscript to the Commissioner of Fisheries on the collections and observations made at one hundred and thirteen marine stations.

The original program for the strictly oceanographic work of the *Arcturus,* as communicated to the writer by Dr. Fish, was as follows:

1. A hydrographic section from the American coast through the Gulf Stream.

2. Several sections through the Sargasso Sea, one to extend from Bermuda to a point south of the Azores.

3. One month at a station in the Sargasso area, for intensive investigation of vertical life zones, for obtaining data on surface evaporation, etc.

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4. Hydrographic and plankton observations in various localities—Gulf Stream, Antilles Current, North Equatorial Current, and various places throughout the Sargasso Sea.

The observations to be made at each station included sounding, at which time a sample of the bottom was to be preserved for analysis of nematodes and diatoms; color and transparency observations; vertical series of temperature and water sample collections, the latter to be titrated for salinity; surface water and air temperatures every two hours; water samples for gold and silver analysis; vertical, horizontal, and closing plankton net hauls at all levels; dredging, and trawling with Petersen young fish trawl in certain localities. In addition to this, Mr. Beebe planned to make observations on the abundance and distribution of weed in the Sargasso Sea area, the gulfweed animal communities, and the deep-sea fishes.

The program was modified considerably later, when the cruising radius of the ship was found to be much smaller than previously supposed, and the crew not sufficiently large to carry on the work laid out. The nature and location of the oceanographic work actually completed in the Atlantic is as follows:

1. A hydrographic and plankton section from 30° N. and 60° W. to a point off Cape Hatteras (36° 55′ N., 74° 12′ W., passing south of Bermuda (July 11-22, 1925).

2. A section from the Mid-Atlantic Ridge (27° 42′ N., 46° 59′ W.) to a point 100 miles N. E. of Sombrero (19° 21′ N., 61° 57′ W.), passing through a part of the Sargasso Sea, the North Equatorial Stream, and the Antilles Current (February 28-March 12, 1925).

3. Surface observations on plankton distribution in the Gulf Stream from Cape Hatteras to a point off New York (39° 24′ N., 71° 42′ W.).

4. Extensive hydrographical and biological collections from all levels at one point in the Gulf Stream, approximately 39° 24′ N., 71° 42′ W.).

5. Hydrographic and plankton data on conditions in the Sargasso Sea area at widely different seasons (February and June), to be used in a study of the seasonal variations in that region.

6. Determination of vertical life zones in the Sargasso Sea and the Gulf Stream, supplemented by similar observations in the Pacific.

It was originally expected that only a short time would be spent in the Pacific, but, after the change of plan, the following oceanographic work was carried out in connection with the visits to the Galápagos and Cocos Islands:

1. A hydrographic section from a point 200 miles off Colombia (5° 02′ N., 81° 08′ W.) to the Galápagos Islands (0° 10′ S., 90° 05′ W.).

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2. Eleven vertical temperature series and nine series of vertical plankton collections in the region of the Galápagos Islands, the most southerly station being located 67 miles south of Hood Island.

3. Concentrated hydrographical and biological investigation at a point on the Coco Plateau (approx. 4° 55′ N., 86° 59′ W.) (May 25-June 3, 1925).

4. Surface and air temperatures taken every three hours.

5. Drift bottles distributed throughout entire area visited.

The objects of the *Arcturus* party as a whole had to do largely with collection and observational studies of sea life of the surface zones and of the fauna of islands visited. The Dunn diving helmet was used extensively, and cinematograph records of much of the field work were obtained. Although the cruise was designated an "expedition to the Sargasso Sea and the Humboldt Current," the leader feels that in the ordinary sense of these terms he "found neither"—the meaning of which phrase he explains in *Science* (*loc. cit.*) and elsewhere.

The *Arcturus* was in the vicinity of the Galápagos Islands during the manifestations of the most remarkable oceanic phenomena of a generation along the west coast of South America. A cross section of the true "Humboldt Current region," extending westward from the coast of Peru in latitude 6° S. or higher, might have yielded sufficient physical data to solve an outstanding oceanographic problem. No such investigation, however, was undertaken.

In his note in *Science,* Mr. Beebe mentions the absence about the Galápagos Islands, during the spring of 1925, of the usual oceanic characteristics associated with the normal flow and upwelling of the Humboldt Current. In referring to a subsequent westward-setting surface movement "as far west as the Marquesas," it is evident that the Current, which is primarily a littoral phenomenon, has here been confused with the prevailing trade-wind drift of the central South Pacific.

Parts of the marine collections of the *Arcturus* expedition have been deposited in the American Museum of Natural History.

INVESTIGATIONS OF THE AMERICAN MUSEUM OF NATURAL HISTORY IN THE HUMBOLDT CURRENT REGION

From December, 1924, until March, 1925, the writer, accompanied by Mr. Van Campen Heilner, conducted marine zoological investigations for the American Museum on the coasts of Peru and Ecuador. A report on the oceanographic phases has since been published (Oceanic and Climatic Phenomena along the West Coast of South America during 1925, *Geographical Review,* vol. 16, pp. 26-54, 1926). This paper is supplemented, moreover, by another of more popular nature (Equatorial Vignettes, *Natural History,* vol. 25, pp. 431-449, 1925).

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The problem on the arid west coast of South America is highly complex. In their incipience, the factors which produce the periodical changes are doubtless purely meterological, while the end stages, because of the peculiar topography of the western watershed of the Andes, involve profound geographic effects. The intervening phenomena in the grand sequence are, however, distinctly oceanographic. The notably stable physical characteristics of the littoral ocean of this coast, and the consequently undue disturbances which occur during the rare cycles in which such characteristics are altered, are alike unequaled elsewhere. In no other part of the world does a simple reversal in direction of the coastwise oceanic circulation lead to such spectacular climatic, biological, and economic results.

The writer worked entirely from launches and other small craft, and his equipment was limited to surface apparatus. His data, therefore, do not lead to an understanding of the extent in breadth or depth of the warm counter-current which for many weeks during the winter and spring of 1925 replaced the Humboldt Current, at least at the surface, bringing about the cessation of cool upwelling and preparing the way for perhaps unprecedented rainfall along the desert coast. Even as regards simple surface temperatures, all the tables thus far obtained from the pertinent section of the Pacific, record conditions only along coastwise tracks, within a few miles of shore. The data urgently needed are routine observations made at right angles to the trend of the coast, and extending for a thousand miles or more along any parallel between the equator and latitude 30° S. Such data, especially if accompanied by subsurface records, might reveal whether the counter-current known as El Niño was in the nature of a restricted coastal tongue or whether the phenomenon represented a surface movement of colossal extent in the wake of retreating high-pressure areas. A search for figures which may throw light upon this question is now being made, with the aid of Dr. Littlehales, of the U. S. Hydrographic Office, and of several cooperating friends in South America.

The precipitation on the coast of Peru during 1925 has been recorded as certainly the heaviest since 1891; but there are reasons for believing that the conditions have not been paralleled during the course of at least six centuries. Prior to March, 1925, for example, the mud walls of the prehistoric fortress of Chan Chan, near Trujillo, still bore clearly the ancient reliefs and hieroglyphics of their builders, but the rainfall of a few subsequent weeks entirely obliterated them. The destruction of life in the sea, through a process which the writer has elsewhere described, was also unprecedented within human memory. Under date of January 30, 1926, Mr. Francisco Ballén, Director of the Peruvian National Guano Administration, writes that probably two-thirds of the sea-bird popula-

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tion of the Peruvian coast, as existing in December, 1924, perished during the following months of unfavorable oceanic conditions.

Fortunately, the serious economic effects of the counter-current and its sequelæ have simplified the study of meteorological and oceanographic problems by encouraging the recording of precise data. Through the interest of the American Ambassador in Lima, of Major Otto Holstein, of Trujillo, and of other friends and correspondents in the service of numerous Peruvian industrial organizations, tabulated records of the climatic and oceanic régime are now being received regularly. These are deposited in the files of the American Geographical Society of New York, and their subsequent interpretation cannot fail to go far toward illuminating our faint understanding of one of the most remarkable geographic phenomena of our time.

American Museum of Natural History,
New York City.

PHASES OF OCEANOGRAPHIC WORK ORIGINATING AT THE CITY OF WASHINGTON AND IN THE SOUTHERN STATES, 1925-1926

W. J. Peters

In reviewing the oceanographic activities of organizations in Washington City and in the Southern States, one is concerned chiefly with certain government bureaus that maintain fleets, the Smithsonian Institution (also a Federal organization), the Dry Tortugas Laboratory and the Department of Terrestrial Magnetism, both of the Carnegie Institution of Washington. As detail is beyond the scope of this report, mere cursory mention of the work or publications will be attempted. The actual field work in many cases has already been, or will be, discussed by other papers in the symposium, although the origin may have been in Washington, where also the results are published.

Under title of "International Ice Observation and Ice Patrol Service in the North Atlantic," the U. S. Coast Guard publishes annual bulletins containing valuable records of iceberg observations, meteorological observations, soundings, surface-water temperatures and salinity. The bulletins for the seasons of 1924 and 1925 contain descriptions of and results obtained with the salinity apparatus designed by Dr. Wenner, of the Bureau of Standards, especially for rapid and accurate determinations at sea. The actual field of oceanographic operations lies beyond the limits assigned to this report.

The Bureau of Lighthouses is not engaged in original research work in oceanography, but has cooperated with other government bureaus and private institutions by making special observations on ocean currents and

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surface temperatures at various lightships. The results are not published by the Bureau.

A résumé of the U. S. Coast and Geodetic Survey oceanographic operations by Captain Parker is as follows:

"Our activities in the region off the coast of the Southern States during the last year in the line of oceanography have been limited to offshore hydrography in the vicinity of Cape Fear River, North Carolina, and on the coast of the Virgin Islands of America. The oceanography work in the vicinity of Cape Fear River has been an exploration of the coastal waters seaward to a depth of about 100 fathoms by the Survey ship *Lydonia*. This work is but a part of the Bureau's project to survey the entire Atlantic and Gulf coasts of the United States in considerable detail, that is, by sounding lines closely spaced, out to a depth of somewhat over 100 fathoms. At present this work on the South Atlantic coast has been accomplished from Winyah Bay, South Carolina, as far southward as Daytona, Florida, and also off Cape Fear, North Carolina. The *Lydonia* is now filling the gap between these two surveys.

"In the West Indies, the Survey ship *Ranger* has just completed a survey of the coastal waters of the Virgin Islands, St. Thomas, St. John, St. Croix, and the small keys adjacent thereto and is exploring the shoals between the Virgin Islands and Porto Rico. In the vicinity of the Virgin Islands, the surveys have been carried off shore to depths of 400 to 500 fathoms.

"In addition to their surveying operations, the party on the *Lydonia* has been experimenting with a new type of echo sounding apparatus devised by the Submarine Signal Company of Boston, and has proved that this apparatus can measure depths with a very high order of precision, even in shallow water. That party has taken hundreds of soundings in depths from 10 to 200 fathoms which agreed with lead line and machine soundings within the probable error of soundings taken by such apparatus. Some difficulties have been encountered because this apparatus was not originally designed for use on small vessels, but these difficulties are rapidly being overcome, and we have every reason to hope that we will shortly substitute this rapid, economical means of sounding for some of the older methods.

"We are now constructing radio acoustic ranging apparatus for the *Lydonia* and expect during the coming summer to fix the geographical position of our soundings by this method, as we have been doing for the last two years on the Pacific coast. We anticipate that we shall have some new problems to solve, due to the fact that this apparatus has not been used heretofore in shallow water such as obtains along the Atlantic coast of the United States; but we believe these problems can be solved and we are hopeful that by next fall we will be locating soundings on the

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Atlantic coast with the same high degree of precision that we are now getting on the Pacific coast.

"This, in brief, sums up our activities on the southern Atlantic coast. We have, of course, been doing considerable in-shore hydrography such as a resurvey of Tampa Bay and several of the sounds and inlets along the south Atlantic, but I take it that these activties do not come strictly within the scope of oceanography."

The work of the Bureau of Fisheries in the region covered by this report is limited to the study of conditions, such as temperatures, currents, sea bottom, etc., favorable for the propagation of oyster culture along the coasts of Texas, South Carolina, and Georgia. Details appear in the Fisheries Service Bulletins. In other regions special temperature and current observations have been made in cooperation with other organizations.

Oceanographic results obtained within the year on vessels of the U. S. Navy are given in the following résumé by Dr. Littlehales:

"Investigation and disproof of reported shoal soundings in charted depths of 100 to 400 fathoms off the coast of North Carolina by the U. S. S. *Nokomis,* November 1925. Sonic soundings from Cape May to Hampton Roads (on the continental shelf) by the U. S. S. *Hannibal,* December 1925. Sonic soundings in the eastern borders of the Bahama Islands by the U. S. S. *Milwaukee,* July 1925.

"Although much work of this nature has been performed in the Caribbean Sea and the West Indies, and in the Pacific, the above mentioned are all the items with which I have been connected in the region specified."

Oceanographic work by members of the Smithsonian Institution include: Miss Rathbun's monographic account of the spider crabs which appears as Bulletin 129 of the U. S. National Museum; continuation of their respective studies of amphipod and isopod crustaceans by R. Shoemaker and J. O. Maloney; the studies of various groups of echinoderms and more particularly the recent crinoids by Austin Clark; the study of marine fishes by B. A. Bean; systematic work on the unrivalled collection of cetaceans in the Museum by G. S. Miller; a report by A. B. Howell on the myology and osteology of the Asiatic finless porpoise based upon collections made during the National Geographic Central China Expedition; a report by L. Stejneger on the fur-seal industry of the Commander Islands.

The oceanographic activities of the Smithsonian Institution are sometimes involved with those of other organizations.

A systematic ecologic study of the decapod crustaceans was made by W. L. Schmitt during a short sojourn at the laboratory of the Carnegie

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Institution of Washington at Dry Tortugas. Also, during a visit to the same laboratory, P. Bartsch, in addition to his systematic work on marine mollusks, exposed 1,600 feet of undersea film with his submarine cinema camera with a view to studying and showing variation of habitat and adjustment of organisms to ecological conditions. A. Mann of the Smithsonian Institution also spent four weeks at the Tortugas Laboratory during which diatom flora were studied and one hundred samples were shipped to Washington for research. They represent a practically complete collection of diatoms living in the vicinity during the month of June.

The activities of the Dry Tortugas Laboratory tend to center at present upon two problems. The first is, in a broad way, the problem of the nature of specific difference, being attacked independently by Bartsch, Graves, Tennent, and Wilson. The second is the problem of specific adaptation to natural environment, on which Longley, Schmitt, and Taylor are working. A number of papers by different authors on various biological aspects of oceanography have been published by the Dry Tortugas Laboratory during the year past, among which are: Volume III of the papers from the Department of Marine Biology of the Carnegie Institution of Washington; Taxonomy of the Amebas with Descriptions of Thirty-nine New Marine and Freshwater Species, by A. A. Schaeffer; Study of the Skull of a Fossil Sperm-Whale, and Additions to the Tertiary History of Pelagic Mammals on the Pacific Coast of North America, by Remington Kellogg.

Oceanographic work of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington has been restricted during the past twelve months, principally to reductions of sea observations, investigations of the results, and publications relating thereto.

Reduction of atmosphere potential-gradient observations made on the cruises of the *Carnegie* to a common epoch 1918.5 shows that it is feasible to construct iso-electric charts for the greater portion of the world. Important conclusions regarding potential gradient, ionic content, and radium emanation over the waters of the globe have been formulated by S. J. Mauchly. Investigations of secular variation of magnetic elements by H. W. Fisk and J. P. Ault show the urgent need of additional data over the oceans. In cooperation with the *Maud* Expedition, valuable data in terrestrial magnetism and atmospheric electricity were collected at the winter quarters, 1924-1925, four miles north of Bear Island, off the Siberian coast. Volume V of the Researches of the Department just published contains the results of cruises made on the *George B. Cluett,* a schooner chartered from the Grenfell Association in 1914, and those

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made on the *Carnegie* from 1915 to 1921 inclusive, besides papers of oceanographic interest by various members of the Department.

Department of Terrestrial Magnetism,
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Washington, D. C.

WORK CARRIED ON IN THE PAST YEAR BY THE BUREAU OF STANDARDS IN THE DEVELOPMENT OF INSTRUMENTS FOR USE IN OCEANOGRAPHIC INVESTIGATIONS

H. C. Dickinson

Abstract.—An informal talk on a few items of interest in the work of the Bureau of Standards, and a few suggestions as to possibilities for the future in the development of oceanographic instruments.

Bureau of Standards,
U. S. Department of Commerce,
Washington, D. C.

OCEANOGRAPHY FOR THE ICE PATROL

Edward H. Smith

Inasmuch as this is the first paper that has been placed before a meeting of the American Geophysical Union by the International Ice Patrol on the subject of oceanography, it will probably not be out of place first to touch briefly upon the history of the Ice Patrol Service. The Patrol was established by an international conference of maritime nations held in London in 1913; one of the problems before the conference being to devise some method whereby life on the North Atlantic should be more carefully guarded against the danger every spring of drifting Arctic ice. The *Titanic* disaster (April 15, 1912) was still fresh in the minds of the public and this without doubt was a great influence moving the London convention to recommend that a continuous vessel patrol be maintained in the ice-infested waters southeast of Newfoundland during the months of April, May and June. The United States eventually undertook the task of providing for such a service and, with the exception of the two war years 1917-18, it has been functioning successfully ever since.

Our government is being reimbursed each year for the expenses attending this humanitarian work by the principal maritime nations of the world, the total bill being apportioned around in accordance with the distribution of ocean-going tonnage. The directive policies and administration of Ice Patrol matters are delegated by executive order to an Inter-Departmental Board consisting of five members. The chairman is Rear Admiral F. C. Billard, Commandant of the U. S. Coast Guard; and it is this branch of the Federal government upon which devolves the duty

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to furnish men and ships for the work. The Ice Patrol has two main aspects, viz., (1) the practical task of locating all ice threatening the steamship tracks, and the disseminating of this information to shipping, (2) the making of such scientific observations and investigations as will lead to a better understanding and administration of the practical work. It was early realized that the Patrol could not give its best efforts to shipping unless a carefully planned scientific program was begun from which conclusions of practical value might be drawn. Dr. Henry B. Bigelow, of Harvard University, was invited to become an honorary member of the Inter-Departmental Board and his services from the outset in a technical, advisory capacity have been invaluable in shaping the course and policies pursued since 1913. Energies directed along the general lines of investigations in both physical oceanography and meteorology have always offered a rich return of useful information; but the Patrol has had difficulty in attracting individuals, in this country at least, who possessed the particular qualifications requisite to head active investigations. The Coast Guard, therefore, during the past few years has encouraged its own officers—one especially—to improve themselves in a scientific way, wisely realizing that the Ice Patrol will give the most efficient economic service to shipping only when useful, scientific methods are employed to support the practical work. Every year the Coast Guard publishes an Ice Patrol Bulletin, consisting of some fifty to one hundred and fifty printed pages and containing a complete report of the work carried out during the current ice season. Parts are devoted to subjects such as ice scouting, the behavior of the ice, and detailed notes and discussions of a meteorological and an oceanographical nature. The pamphlet is well illustrated with photographs, sketches, and charts, and gives considerable space to a discussion of the circulation of the waters patrolled by the ships—a region of the North Atlantic than which none is more interesting in its hydrographical phenomena.

A review of the scientific activities over the period which has elapsed since Ice Patrol inauguration shows that during recent years especial emphasis has been placed upon the practice of physical oceanography. If we trace events more in detail, we observe that explorations downward in the waters of the Labrador Current and the Gulf Stream were begun by the Patrol as early as 1914; but aside from collecting and publishing the data nothing was done until 1921. That year a definite program of physical oceanography was put into effect by the Inter-Departmental Board and attempts were made for the first time to draw lessons of practical value from the material collected. The following year marks another advance, when an individual familiar with both the technical and the natural problems of the Patrol remained continuously in the ice regions, transferring from ship to ship, as each one in turn exchanged

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sea duty for a relief in port. In 1922, a more intensive application of oceanography was entered upon when both ships were equipped with instruments and gear in contrast to former years when only one of the vessels had been able to carry out sub-surface investigations. Oceanographic work has been pursued since that time along plans as laid down from year to year. It may be surprising to learn that the Ice Patrol to date has collected some 3,000 sub-surface observations of salinity and temperature in the waters south and east of Newfoundland. The basis of evidence in drawing conclusions is mostly in the form of salinity and temperature distribution at various levels, and as checked wherever possible with the drifts of icebergs, some of which the Patrol has followed for weeks at a time in journeys as great as four hundred miles. Now we are beginning to see more clearly, as a result of such a compilation, the general scheme of circulation (and its seasonal processes), from St. Johns southward over the Grand Banks and off-shore into the Atlantic basin, past the slopes of which skirt the northern waters of the Gulf Stream. Discussions in detail, and conclusions, are contained in the reports of the Patrol for the years 1922-24, Bulletins 10 to 12, inclusive. This knowledge, it is worth noting, forms the principal guide upon which the Patrol vessels base their plans of scouting and also their dissemination of advice to shipping. In 1924, the Coast Guard, desiring to secure the greatest advantages offered by recent developments in oceanography, sent one of its officers to take a course of study and research with Professor B. Helland-Hansen at Bergen, Norway. The Ice Patrol material was treated at Bergen to dynamic calculation, especially that material which had been collected from around the Tail of the Grand Banks where the Labrador Current and the Gulf Stream meet. This is without doubt one of the most interesting areas of the entire North Atlantic, containing as it does some of the greatest hydrographical extremes to be found anywhere in the world. As a result of the investigation five different types of interaction between the two mammoth currents have been ascertained. Besides doing the statistical work the Coast Guard had another object in view in sending a representative to Europe which can best be described by the following remarks:

One of the most important natural problems which has confroned the Ice Patrol has been the securing of advance information regarding the probable drift of ice after it arrived at the gateway to the Atlantic (the vicinity of the Tail of the Grand Banks). If we glance at a general map of the northwestern North Atlantic, we may trace with a pencil southwards along the continental slope from Baffin Land to the Tail of the Grand Banks, without great change in direction for a distance of 1,800 miles, the general course followed by both the current and the ice stream. The cold Arctic water in it is discharged past the Tail of the Grand

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Banks being no longer preserved by the general trend of the continental slope, is forced to meet directly the easterly moving masses of, or associated with, the tropical Gulf Stream. It is at this point that the course of the current, and likewise its freight of drifting ice, is subjected to great variations in direction. It is naturally extremely important information to the Patrol (for dissemination to shipping) whether the ice will be deflected northward again into the shallow shelf waters, or whether it will be swept southward across the North Atlantic Lane Routes, which in the latter case creates a grave menace to navigation. If the Patrol had knowledge of the drift tracks which bergs would follow after arrival at the gateway to the Atlantic, much more detailed information could be furnished to approaching vessels, especially during the protracted periods when fog enshrouds this cold water region. It has been found that the drift of nearly all bergs is primarily controlled by relatively deep-seated ocean currents and that the effect of the winds, such as those which usually prevail from April to July in this region, is practically nil. A monthly current map (for oceanic circulation does not fluctuate so rapidly as does the atmospheric) of this critical area where the Labrador Current and the Gulf Stream meet, is an indicator of the courses the ice will tend to follow. It is just herein that modern methods of oceanography as taught and employed by Helland-Hansen, and a few other European oceanographers, have a practical application for this particular problem confronting the Ice Patrol.

That part of oceanography upon which Helland-Hansen and Nansen are laying great emphasis these days, has a foundation which really goes back to the dynamic laws for the air and the water as brought out by Bjerknes in 1910. The feature of their methods centers chiefly upon the manner in which Bjerknes' formulæ of free motion have been developed into a form extremely applicable to the sea. Helland-Hansen, it is safe to say, has achieved more success in this line than any other one oceanographer. He and Nansen are at present bringing out a work on the eastern North Atlantic which employs these methods almost exclusively. The course of lectures as given at the Geophysical Institute in Bergen deals with an introduction to the general schemes of circulation as illustrated in various sea basins; the causes of ocean currents; hydrodynamics; Bjerknes theory; and the methods found best to illustrate calculated motions. The arrangement and development of subjects has been well considered so that if we have given the temperature and salinity from several known depths at stations scattered netlike over an ocean area to be surveyed, then the direction and the velocity of the currents are easily calculated and mapped. Several current maps for the ice regions have thus been drawn proceeding first through the preliminary steps of computing the dynamic depths of the selected

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isobaric surfaces. In this connection it may be remarked that the direction and velocity of the currents as drawn on these maps agree very closely with the direction and the rate of drift of the ice as observed by the Patrol quite independently in the same region and at the same time. This method of so called "dynamic oceanography" provides an easy and efficient method for mapping currents over extensive ocean surfaces, a feature which is bound to guarantee a great employment of it in future hydrographical surveys. Coast Guard Bulletin No. 14, soon to be received from the printer, contains a simple exposition of the foregoing methods written primarily for the furtherance of the Ice Patrol work.

The program which it is hoped will be carried out this season, the first data from which are now being collected as this paper is being written, will consist of a maximum number of oceanographic stations distributed over the water south of Newfoundland which the icebergs soon will commence invading. In order that the work may be carried out in a minimum of time (for oceanographic work on the Patrol is secondary to that of ice scouting), the survey is based on a series of lines of stations running off-shore in a direction normal to the general trend of the Grand Bank slopes. Stations are being taken every 20 to 30 miles apart and extended off-shore from the edge of the Newfoundland shelf for a distance of 60 to 150 miles. The interval between lines of stations averages 100 miles, and the first line is taken on the southwest slope of the Bank beyond a point at which the ice is turned in its course. The station lines follow eastward at intervals along the continental slope and thence northward as far as time permits. It is hoped from the data collected in this manner to keep an up-to-date current map on board the Patrol ship and thus be able to foretell the paths which icebergs will follow after arriving near the juncture of the Labrador Current and the Gulf Stream. The success or failure of forecasting by such a program as outlined, depends to a great extent upon the rate at which variations take place in courses of the currents. Obviously, little reliability can be attached to a monthly current map if important changes occur in the circulation from day to day or week to week; but investigations made at Bergen with the Ice Patrol records of previous years would indicate that the alterations in direction and velocity of the current take place so slowly that the dynamic topographical maps (current charts) will be reliable up to two or three weeks. Several interesting discoveries were brought out in the course of the research work at Bergen last year, a few of which we may allude to briefly here. The famous "cold-wall" which is so clearly delineated along the entire American coast and which extends with marked clearness just south of the Grand Banks does not denote the boundary between the Gulf Stream and the variable counter set inshore as is commonly supposed. The

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change in direction of flow on the contrary is located at the density-wall, and this phenomenon, it was found, lies 20 to 30 miles inshore of the famous cold-wall, near the Grand Banks. This is a feature which deserves considerable attention and future thought. It may be a hydrostatic phenomena attributable to the cold inshore (and relatively fresh water), salting faster than it warms; but in any case it results in a voluminous amount of the icy water of Arctic origin flowing in the same direction and parallel to the Gulf Stream. The dissimilarity, too, between the position of the cold-wall and density-wall, more or less confounds a view heretofore held by many that an intensive sinking (Cabbeling) of the water (especially from the Arctic) is constantly taking place along the length of the cold-wall. Further, the belief is not tenable that the Labrador current dives beneath the Gulf Stream, for as a matter of fact the edges of these two currents have about the same density where they meet. The resulting mixture it is true (as proved by hydrographical tables) is denser than either one, but even this can cause no actual sinking of the water particles while steady conditions prevail, because our rotating earth relegates free movements solely in a lateral direction and making an angle of ninety degrees with the density gradient. The extent to which this influence of so-called cabbeling reaches, of course, can be greatly magnified through alterations in the acceleration of water masses, and in such a region as south of the Grand Banks where intensive mixings and interactions are in process, dynamic laws such as specified by formulæ must be applied with qualifications. This is a subject which is worthy of an oceanographer's attention.

Perhaps it would be of interest to mention an apparatus now in operation on board the Ice Patrol ships which furnishes a practical shipboard method for the immediate determination of the salinity of water samples. The instrument is housed in a cabinet of convenient size and permits an unskilled operator by a principle based upon the variation in the electric conductivity of sea water, quickly and accurately to determine the salinity of a given sample. The final design of this successfully operating instrument is due to Dr. Frank Wenner, U. S. Bureau of Standards, who plans to publish in a forthcoming issue of an American instrument journal a detailed account, with illustrations, of the apparatus. Those who may be interested in the actual operation of the instrument under shipboard conditions are referred to an account in U. S. Coast Guard Bulletin No. 12, for 1924.

One of the two Ice Patrol ships, the *Tampa,* is equipped with a sonic depth-finder such as used in the U. S. Navy and as designed by Dr. H. C. Hayes. Primarily, it was placed on board in order that experimental tests might be carried out on locating the position of icebergs by submarine echo. It was thought that an adaptation of the device might

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serve as an iceberg alarm for trans-Atlantic steamers. In addition to such experiments, a secondary program has been formulated whereby a formidable compilation of hydrographical soundings will furnish the material for revising present bathymetrical charts long known to be inaccurate in the Grand Banks region. Last year was the first time that the sonic was used by the Patrol. An account of the results obtained is carried in Coast Guard Bulletin No. 13, for 1925.

The writer in the course of the past two years has had an opportunity to meet many oceanographers in Europe and also was able to attend the annual meeting of the International Council for the Exploration of the sea in 1924. One cannot fail to be impressed with the thought, time, and money which is being devoted to the subject of physical oceanography abroad. Energy directed along such lines is prompted no doubt by a shrewd, long-sighted policy of fisheries conservation, but this stimulation of thought on oceanographical subjects, regardless of its causes, has developed and cultivated a point of view in a wide scientific circle, the parallel of which does not exist in the United States as yet. It must generally be admitted that in America we have slighted lamentably the practice of physical oceanography. This neglect appears strikingly when we turn to the list of attainments in contemporary sciences. It is all the more gratifying at this time to learn, therefore, of activities such as are reported for example by the Scripps Institution at La Jolla on the Pacific coast. Various suggestions for a program with the character of a systematic undertaking applied to the Atlantic waters along our eastern shores, come rushing to mind. The Ice Patrol unofficially, we might add in closing, has had under advisement for some time a possible expedition which would carry out a sub-surface investigation of the waters along the American continental slope from Newfoundland northward into Baffin Bay. The principal incentive, of course, is the desire for a complete history of the behavior of ice from the time it leaves the Greenland glaciers until it finally melts in the warm off-shore waters of the Atlantic basin.

The American Geophysical Union, by stimulating thought, coordinating efforts, encouraging interest all along oceanographical channels, is placed today in a most influential, responsible position.

U. S. Coast Guard,
Washington, D. C.

RECENT DEVELOPMENTS IN ACOUSTICAL DEPTH-FINDING APPARATUS

HARVEY C. HAYES

Various methods and means for determining ocean depths by sound waves have been developed during the past few years, most of

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which have certain specific merits, but no one of which operates entirely satisfactorily over the whole depth range. Depths less than about one hundred fathoms are measured with considerable accuracy by any of three types of apparatus developed respectively by Dr. Alexander Behm of Germany, Dr. M. Langevin of France, and by the Submarine Signal Corporation of Boston, U. S. A. All three types register the depth in terms of the time of sound transit to the sea bottom and return by flashing or deflecting a spot of light on a scale.

During the past year the Navy has developed two distinct types of depth-registering devices which, in addition, are able to record the depth and to sound an alarm when the ship passes over any predetermined depth to which the apparatus is set. But all of these registering and recording devices fail at the greater depths because the intensity of the echo then becomes so weak, compared with that of the local disturbing noises produced by machinery, propellers and slapping of waves, that sufficient amplification to operate the relay or other deflecting parts of the apparatus cannot be secured by amplifiers without, at the same time, amplifying certain components of the intense local sounds to the point where they also operate the recorder. Thus far no depth registering or recording apparatus has been perfected that will operate reliably in depths much greater than one hundred fathoms.

The intensive research in submarine acoustics which the Navy has carried on during the past nine years has demonstrated that, on shipboard at least, the ear is greatly to be preferred to any mechanically registering or recording device because of its comparative high sensitivity and because it can take into account only such of the numerous received sounds as apply to the purpose at hand. The ear can detect the faint echo of a sound signal of definite known pitch in the midst of numerous intense local noises when other receivers would fail to register anything but these intense local sounds. It is for this reason that practically all the sound-detecting and direction-finding devices, as well as acoustical range-finding devices, developed by the Navy have been designed primarily as aids to the ear. And until some sound-registering or recording device having far greater sensitivity and selectivity is perfected, we believe the most promising line of development of depth measuring, or other apparatus depending upon the reception on shipboard of submarine sound signals, will make use of the ears for receiving the sounds. Under such conditions the depth must be determined by apparatus that can be adjusted to give to the sound signals some particular characteristic or condition that is affected by the depth and that is recognizable by the ears.

Our researches have shown that the simultaneous arrival of two like sounds, one at each ear, can be judged to within one one-hundredth

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thousandth of a second and that for two unlike sounds of approximately the same intensity such judgment can be relied upon for an accuracy to within a hundredth of a second. The great gain in accuracy given by the use of like sounds is due to the fact that the binaural sense then operates to give the listener a sense of direction. This sense is entirely lacking when the two sounds are unlike. The Sonic Depth-Finder was designed to give a sounding in terms of the adjustment of apparatus required to make two like sounds arrive simultaneously at the two ears because the accuracy of such a binaural adjustment even when roughly made, would be sufficient to give the depth with a very high degree of accuracy. In practice, however, it proved that change in depth during the signal interval and variation in the speed of the transmitting cam-wheel are sufficient to prevent the operator from adjusting the two signals sufficiently near to simultaneity to bring the binaural sense into play except under very favorable operating conditions such as are given by smooth sea surface and practically level sea bottom. In general, the accuracy of adjustment to simultaneity of the two sets of signals was found to be even less than that given for two dissimilar sounds, because, in the process of adjustment, as soon as the two sets of signals begin to overlap they tend to coalesce so that their ends become blurred and it is impossible to judge with great accuracy when the signals are superimposed length for length. It proved that an experienced operator can make a depth determination accurate to within about plus or minus five fathoms.

An error of five fathoms is not a serious matter for depths greater than about a hundred fathoms—the range over which the sonic depth finder is capable of operating—but for depths under one hundred fathoms it becomes necessary to obtain greater accuracy. Somewhat over a year ago the Naval Research Laboratory undertook the problem of developing an acoustical depth-finder that would cover the whole range of ocean depths and give a higher degree of accuracy than the original device, which originally was developed for a range-finder and not a depth-finder. This problem has been fairly well solved; and its solution represents the only progress made in acoustical depth-finding apparatus during the past year that has come to our attention.

The new device employs the same procedure on the part of the operator as does the sonic depth-finder, which consists of adjusting the apparatus so as to cause two systems of equally spaced signals to arrive simultaneously at the two ears. Except for this one similarity, the principle of operation of the new device differs radically from that of the old one. The old device employs the same pitch for both sets of signals and brings them to coincidence at the ears by adjusting the period between signals, so that the time of sound transit to the sea

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bottom and return shall be a whole multiple of this period. The new device employs a decidedly different pitch for the two sets of signals. It does not vary the periodicity of the signals, but instead provides means for generating the comparison signals at any desired instant after the generation of the submarine sound signals. By this means the comparison signals can be delayed behind the sound transmitter signals so that they will energize one phone of a double telephone head set at the same instant that the echo of the submarine sound signal is picked up by a submarine sound receiver and heard in the other phone. The time of sound transit to the sea bottom and back is then equal to the known time the comparison signals are delayed behind the sound signals. Such an arrangement permits the adjustment to simultaneity to be made for any depth independent of the length of the sound signals, but the original device only permits such adjustment for depths beyond which the time of sound transit is greater than the duration of the signals, thereby rendering it useless for depths of less than about twenty fathoms.

The use of a distinctly different pitch for the two sets of signals not only removes most of the coalescing and blurring troubles experienced when like signals are used but, strange to say, permits the use of the binaural sense in making the adjustment for simultaneity so that this adjustment can be made with a high degree of accuracy. The explanation of this unlooked for result appears to be simple and is as follows: Two pure sounds of slightly different pitch are near enough alike to cause the binaural sense to operate and give a sense of direction. This is readily proved by holding two tuning forks of slightly different pitch at the two ears respectively. If the higher pitched fork is held at, say the right ear, the sound appears to the listener to come from his left and to move across to his right and these excursions continue periodically, the period being equal to the beat period given by the two forks. These excursions become more rapid as the pitch difference between the forks becomes greater and appear to vanish when their frequency becomes something like fifteen or twenty per second, or in other words, when the period between beats is of the same order as the time interval of vision persistence. When the beats occur so rapidly that the mind cannot comprehend each separate excursion of the sound image, the sense of direction vanishes and the two distinct pitches are heard, one at each ear. And since under such conditions there is no unwilled effort to determine the direction of the sound, the operator is as free to listen for sound from any definite direction as he would be when the forks are silenced. If the two fork sounds of different pitch are now broken up into short dash-like signals and the listener focuses his attention for a sound, say straight ahead, he will hear a sound in that

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direction if the signals reach the two ears in such a way that their first exposure together is made when the sound waves are in phase. This does not mean that the front end of the two signals reach the two ears simultaneously, but that when the later one reaches its respective ear it will be in phase with that part of the earlier signal that is already stimulating the other ear. The first binaural exposure will then be the same as that given by a sound source dead ahead and if the listener's attention is focused for a sound from that direction he will have a distinct impression that a sound is actually coming from that direction.

If the foregoing explanation is correct then when the two signals of different pitch are adjusted for a binaural center the greatest difference in time of arrival at the two ears will equal one second divided by the difference in the pitch of the two sounds. The average difference will be half of this value. Laboratory tests employing 1060 for the pitch of the sound signal and 1325 for that of the comparison signal have shown an actual average error from the adjustment to perfect simultaneity of the order predicted and in terms of depth soundings represents an average error of 0.8 fathoms and a maximum error of about 1.6 fathoms.

This type of depth-finder has been tested on one ship, the U. S. S. *Hannibal,* with favorable but not wholly satisfactory results, because the relative location of the submarine sound transmitter and receiver on the *Hannibal* is such that the direct sound from the transmitter energizes the receiver so strongly that it responds to this sound, which it is not desired to hear, more intensely than it does to the echoes of the signals. As a result, only soundings in shoal water, where the echoes are very intense, could be taken. However, the tests demonstrated the ability of the device to take accurate soundings to depths as shoal as six fathoms and there is all reason to believe that it will work at the greater depths when installed on a ship carrying a submarine sound receiver well shielded from the direct sound of the transmitter.

Naval Research Laboratory,
Bellevue, Anacostia, D. C.

A NEW BASE MAP FOR THE OCEANOGRAPHER

W. E. JOHNSON

Wherever oceanic information is exhibited in graphic form one thing is notable, and that is the great distortions of relative area and linear representation, due to the use of Mercator's Nautical Projection as a base. Instruments and methods have been devised for securing and recording data and a number of nautical organizations are co-operating in collecting it. Thus, many data are being assembled, but an adequate instrument

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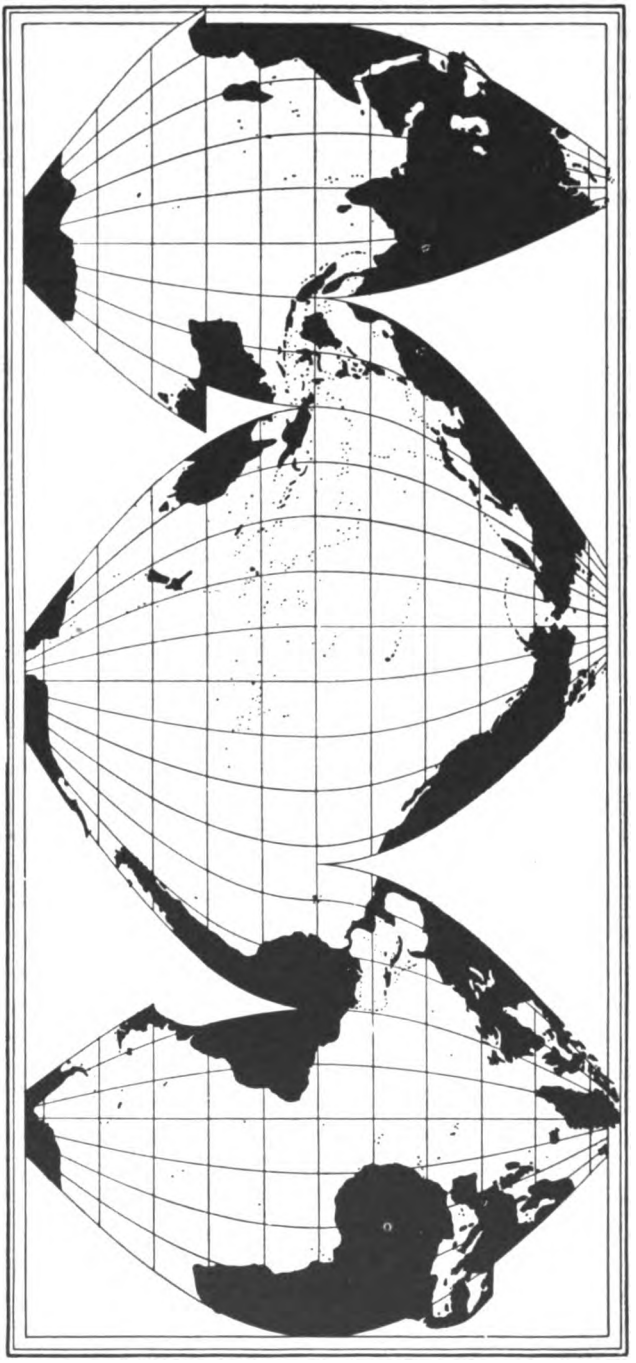

FIG. 1

The oceans of the world on Mercator equal-area projection

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for the proper exhibition of these data has been lacking. To supply this deficiency an equal-area map of the oceans was devised. It represents an effort on the part of the cartographer to serve the oceanographer.

The scale of the map will be 1:40,000,000, about 550 nautical miles to one inch. This allows a maximum size for convenient handling, 22 by 44 inches, including a 2-inch margin all around. The advantages of the projection chosen are several:

1. It is an equal-area projection, that is, true for area scale throughout; a square inch on any part covers the same "ground area" as a square inch on any other part.

2. It gives true linear scale for all measurements paralleling the equator and on the vertical meridians of each figure. Other linear measurements, however, are variable.

3. It provides an unusually convenient base for plotting data, since the intervals between parallels are true and the meridional divisions along each parallel are true and equal. This permits the use of a degree scale for use throughout the map and uniformity in plotting.

4. It allows the map to be divided to show each ocean to advantage and yet to make a continuous and comparative whole.

This particular projection was selected as a base only after careful consideration of available equal-area projections. The so-called "Conic" equal-area projection, Albers and Bonne, would necessitate the division of the world into north and south hemispheres with a resulting split along the equator, thus dividing the very areas we desire to hold together. The homalographic, although somewhat similar to the one used, has distortions of shape (as much as 25 per cent) in the equatorial belt, contracting the equatorial distance and increasing the scale on the meridians as they cross the equator. This distortion is then reversed in the higher latitudes. The Aitoff's (Hammer's) is not adapted to the staggered split necessary to divide the oceans properly. In addition the parallel and meridional intervals are irregular and therefore would not be as convenient for plotting, since each quadrilateral would have to be divided separately.

The projection used is the Mercator equal-area—so named because it is first found in Mercator's Atlases of 1606-7-8 and -9. It has subsequently been called Sanson-Flamsteed and Sinusoidal. Sanson did not use it, however, until 1650, over 40 years after Mercator. Flamsteed used it first in 1729. Therefore, in justice to Mercator, we have given

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it his name. That Mercator used it, evidences his appreciation of mass representation as regards relativity in contradistinction to conformality in his nautical projection.

U. S. Coast and Geodetic Survey,
Washington, D. C.

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SECTION OF VOLCANOLOGY

(Washington, D. C., April 29, 1926)

SYMPOSIUM ON SCIENTIFIC CO-OPERATION IN THE ALEUTIAN ISLANDS

SCIENTIFIC CO-OPERATION IN THE ALEUTIAN ISLANDS

T. A. Jaggar, Jr.

The topic for the symposium was suggested by the immediate prospect of the founding of a volcano observatory in the Aleutian Range under the United States Geological Survey. The Aleutians are difficult of access and remain but little more explored than when Alaska was first acquired. The region of greatest interest is the Andreanof group about Atka, between the Islands of the Four Mountains and Tanaga. This region has hitherto defied all attempts at mapping, collections, soundings, and geophysical measurements, beyond the barest reconnaissance. There are here thirty unknown volcanic islands, in the latitude of southern British Columbia (52°), in the middle belt of the Aleutian arc, in a length of 350 nautical miles. The climate is mild, but windy and foggy.

For the proper conducting of all kinds of scientific investigations for years to come, about Atka as center, three things are essential; (1) the erection and manning of a permanent geophysical station; (2) the permanent co-operation of a government bureau that operates boats; (3) co-operation of several establishments, governmental or otherwise, in expense.

In this region the U. S. Geological Survey and the Geophysical Laboratory of the Carnegie Institution are interested in volcanoes; the Department of Agriculture is interested in climate, soils, biology, and forestry; the Coast Survey is interested in charts, soundings, gravity, magnetism, primary triangulation, and seismicity; the Navy is interested in Coast Guard operation, wireless, aviation bases, navigation, and oceanography; the Army is equally interested and has been located in Alaska many years; the Smithsonian and the National Museum are interested in the ethnology and natural history; the Department of Commerce is interested in lighthouses, transportation, fisheries, mining and trade; all are interested in topographic mapping, whether by air, land, or sonic sounding.

It is hoped that this symposium will develop the possibilities of a genuine cooperation.

Hawaiian Volcano Observatory,
Hawaiian Islands.

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THE ALEUTIAN ISLANDS FROM THE STANDPOINT OF THE GEODESIST AND CHART-MAKER[1]

WILLIAM BOWIE

No matter what the study of a large area of the earth's surface may be, an essential factor in the successful working out of the problems and their solution is the knowledge of the geographic positions, elevations and configuration of the ground. Without such data, one works largely in the dark.

As far as the Aleutian Islands are concerned and the regions of Bering Sea and the Pacific Ocean nearby, which would be involved in any investigation covering the islands, we have scant data. It is true that the islands are shown on charts, but are they in their correct positions? The chances are that they are not. A glance at the charts covering the islands will show that beyond Unalaska Island there are exceedingly few soundings, certainly not enough to afford any idea of a detailed nature as to the configuration of the bottom of the Pacific Ocean and Bering Sea near the islands and the degree of slope out to deep water.

The approximate elevation of some of the islands has been obtained by various means, but detailed topographic work has not been done on any of them, except for the shore line of islands between the Alaska Peninsula and Unalaska Island. Very little shore-line data have been secured on the Bering Sea side of the peninsula and islands.

It would seem that it is essential to have as accurate geographic positions of the islands as may be possible, a determination of the elevation of peaks and a knowledge of the configuration of the terrain of each of the islands. All of this work could be done easily but, necessarily, it would require time and money. The days on which a surveying party can work on the Aleutian Islands are few in number because of rains and fogs.

As far as the soundings are concerned, there should be detailed soundings around each island to show the configuration of the bottom out to the thousand-fathom curve. There should be additional soundings at right angles to the axis of the chain of islands from the 1,000-fathom curve across the edge of the shelf, across any deeps that may parallel the chain, and then out into the main body of Bering Sea and the Pacific Ocean. With such information we should be able to take further steps in studying the history of the islands from the geological and geophysical standpoint.

It would be well if current surveys could be made in the vicinity of the islands with a view to learning whether the drift of water is towards or from Bering Sea or parallel to the axis of the chain. With a knowl-

[1] Read by the Secretary.

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edge of the currents, we should be able to understand better the distribution of the fauna and flora.

The geodetic problems involved in the Aleutian Islands would be the determination of the latitude and longitude of the various islands, the observations for deflection of the vertical, if this is possible, and the determination of the value of gravity. The islands do not lend themselves readily to the determination of geodetic positions, except in a few cases. The customary means of determining positions is triangulation, but this involves the measurement of a base line and of the angles of triangles of which points on the islands form the apexes. Where the islands lie in groups it is possible to get well-formed triangles by means of which geographic positions can be carried with accuracy from island to island, but where the islands are strung along in a line, triangulation is valueless or almost so. Besides, errors are likely to accumulate to a great extent when long distances are covered.

Where triangulation is not possible, distances between two contiguous islands of the chain may be determined by dead reckoning with a ship. The effect of current could be largely eliminated by running the ship between the islands in both directions and then taking a mean of the distances. As a matter of fact, it might be possible to carry the azimuth through the chain of triangles just as might be done in a traverse overland. This would involve the reading of horizontal angles at each of the islands of the chain. With these azimuths and such triangulation stations as are possible and the determination of some distances by means of the ship, a fairly good location of the individual islands, might be made.

It is possible that, some day, a new method will be developed for the determination of distances between islands, which would involve the velocity of light. Professor A. A. Michelson is at present working at Mt. Wilson Observatory, on the problem of determining the velocity of light. The Coast and Geodetic Survey has measured very accurately a base for that work and Professor Michelson expects to secure an accuracy in the velocity of light redetermination of about one part in 100,000. If he does this, and if his apparatus can be easily used in the field, then it may be possible that we can use the velocity of light to determine the distances between island stations. If this method is found to be practicable, then much improvement can be made in island location over what is now possible.

If it were possible to get very accurately the geographic positions of island stations, then, by a comparison of the geographic positions determined astronomically and by triangulation or otherwise, we could get deflections of the vertical which could be used in a study of the devia-

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tions from normal densities in the region surrounding each of the astronomic stations.

Although we may say that we determine by the deflections of the vertical and the value of gravity the deviations from normal densities in the material of the Earth's crust, it may be said with equal exactness that what we do is to measure the differences in weight of blocks of the Earth's crust. Of course, the use of the word "block" must not be taken literally for there is no such thing as an independent block of the crust. The crust is continuous throughout; but it is easy to form a mental picture of what is done by assuming that the Earth is made up of separate blocks with cross sections of approximately 50 or 100 miles square.

The values of gravity should be determined by approved methods on many of the Aleutian Islands and we should also obtain, if possible, gravity observations at sea such as those now being made by Dr. Vening Meinesz of the Dutch Geodetic Commission. As is well known, he has successfully determined values of gravity at sea by swinging pendulums on a submerged submarine.

With the data mentioned above, we should be able to test the isostatic condition of the Earth's crust under the islands and in the water areas contiguous to them. As far as geodetic work is concerned, this would be all that is necessary or that could, under any circumstances, be accomplished. With a knowledge of the isostatic condition of the crust, then we should be able to attack the problem of how the crust in this region is maintained in equilibrium or why it might be out of equilibrium, if the adjustment is found not to be perfect. Beyond the proving of the degree of perfection of isostasy by means of deflection and gravity stations, the geodesist cannot go. If he works beyond that point, he is operating in the field of geophysics and geology.

U. S. Coast and Geodetic Survey,
Washington, D. C.

Discussion

Prof. Brown mentioned the calculations of Jeffreys, which indicate that a large fraction of the energy dissipated by tidal friction is dissipated in Bering Sea. This is an additional reason for getting more accurate data on the currents about the Islands. Some data were collected by governmental vessels a few years ago, but have not been made publicly available.

Mr. Sargent mentioned the organized aerial photographic mapping in southeastern Alaska which is planned by the Navy for the summer of 1926, and its possible extension later to the north and west.

Mr. Sosman mentioned the hypothesis that the dissipation of tidal

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energy in northern latitudes, such as Bering Sea, would give a twist to the Earth, and showed that this is not a necessary consequence, for the point of application of the resultant retarding force might be far distant from the point of absorption of the energy.

PROGRESS IN THE DISCOVERY OF VOLCANIC CRATERS ON THE ALASKA PENINSULA

R. H. Sargent

Abstract.—Mr. Sargent gave a description, illustrated with lantern slides, of two new craters on the Peninsula to the west of Aniakchak crater which was explored a few years ago. The first of the two is much smaller than Aniakchak. The second is of large size, with a higher rim than Aniakchak, and a diameter of several miles. It is at present filled with snow and ice which supply a number of glaciers on the sides of the mountain, but there is evidence that it has been active in recent times. Descriptions and maps will be published later by the Geological Survey.

U. S. Geological Survey,
Washington, D. C.

MAGMATIC PROBLEMS OF THE ALEUTIANS

C. N. Fenner

So little is actually known about the igneous rocks of the Aleutian Islands that it might seem as if there were little more to say on the subject of magmatic problems than that the whole field lies before the investigator.

That can indeed be said, and it can be said further that the region is especially favorable for investigation because of the great number of active and extinct volcanoes situated along this chain of islands; but it is possible to suggest two or three more specific problems.

The chain of the Aleutians forms part of a volcanic range of great length. To the east and northeast it is continued without interruption through the length of the Alaska Peninsula, and still farther to the northeast along the shore of Cook Inlet. The westernmost active volcano, so far as known, is situated on Little Sitkin Island, and the one farthest to the northeast is Mount Redoubt. The arrangement of the vents takes the form of a broad arc nearly 1,500 miles in length. It is fairly certain that in former times activity extended farther to the westward. Buldir is described as an eroded volcanic cone, and Attu is said to be composed of pre-Tertiary igneous rocks. Possibly at the other end there may have been a prolongation beyond Redoubt. There are at least forty vents which have been active within historic times.

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A remarkable characteristic of the chain is that it pursues an uninterrupted course across the most varied terrestrial features. At its northeast end it lies among high mountains and within a region which is apparently truly continental in character; along the Alaska Penisula it is still within the continental border, but the average elevation of the surface has become much less; in the Aleutians the volcanic islands form the summits of a narrow ridge rising abruptly from abysmal depths.

According to present ideas of isostasy, the different elevations of the regions traversed are the expression of something fundamentally different in the character of the underlying material within the upper sixty or seventy kilometers of the Earth's crust, and this line of volcanoes cuts across these features and brings up samples of the underlying material for examination. It is not possible to say from how deep a source the material is drawn, but, to judge from the great length of the line and the great activity displayed along it, the fracture probably reaches a profound depth. A study of the eruptive material in its relation to these features should give interesting information. Though there may be considerable variety of lavas extruded from time to time at any one place, still we should expect that the average product from a volcano in the western Aleutians would be of greater specific gravity than the average in the Katmai region, for instance, and still heavier than that from Iliamma or Redoubt. If no such relation is brought out, the information will still be of value, as it will indicate that the immediate source from which volcanoes draw their supply is much above the depth of compensation.

A second problem for investigation has certain points of contact with the last, but also introduces some quite different questions. It is suggested by certain work I have done on Katmai rocks.

Almost no information is to be found in the literature regarding the chemical composition of the rocks of this whole volcanic chain. We have reports of andesites, basalts, and diorites at various points, but very few analyses. To remedy this in some measure I have made analyses of eighteen specimens from the Katmai district,[1] and the results are represented on a diagram on which the basic oxides are plotted against silica. The rocks range from an olivine basalt, with about 54.5 per cent silica (calculated on a non-volatile basis), to the very siliceous soda rhyolite of the 1912 eruption, with about 77.5 per cent silica. Included in the collection are lava flows from several volcanoes, dike rocks, and plutonics. Their age probably ranges from well back in the Tertiary to the present.

[1] These analyses, and other matter relating to the Katmai region, will be published shortly in a separate article.

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A striking feature of the diagram is the nearly rectilinear distribution of the constituents. It serves as a pronounced family characteristic to unite rocks of very different age, composition, and mode of occurrence. There can be little doubt that all these rocks have a common ancestry.

These rocks are from one small section of the volcanic chain. Naturally, one wonders whether the same characteristics hold as we move away from the Katmai district to the northeast and southwest; or, if not, in what manner a change expresses itself in terms of geographic distribution. Available analyses are too few to give much information on this matter. On a second diagram the results of recorded analyses have been plotted and these have been supplemented with four new analyses.

Several of the analyses fall fairly close to the lines of the Katmai diagram, but on the whole the variations are rather large, and some depart widely. A specimen from Bogoslof Island is an extreme variant. Bogoslof seems to offer, both in its remarkable behavior and in the unusual character of its rocks, an especially interesting object of study. Its lavas ought to be compared with those of the adjacent islands, which are situated more nearly along the direct line of the chain.

The character of the Katmai diagram is doubtless the expression of two factors: (1) the sort of material on which differentiation starts to work; and (2) the processes of differentiation by which changes are brought about. With similar information to that of the Katmai district obtained from several other points along the chain, we should have a much better basis than now from which to draw conclusions on both these points and on other fundamental problems in petrogenesis and volcanology.

A third problem is suggested by the simultaneous activity of Bogoslof and Augustine in 1883. In October of that year, when New Bogoslof rose from the sea, Mount Augustine became active for the first time in recorded history. Both eruptions are described as violent. At the same time two other volcanoes, probably Shishaldin and Akutan, emitted smoke and steam. There is a suggestion here of sympathy of activity, though the phenomena may represent merely a coincidence. There is a similar suggestion in the close correspondence of eruptive manifestations of Pelée and La Soufrière in the West Indies in 1902, and in the reported simultaneous activities of several Japanese volcanoes along the Kirishima zone during the violent eruption of Sakurajima in 1914. It would be of value in forming a conception of plutonic conditions, to know whether there really is, at times, sympathetic activity. A record of phenomena at vents along an extended chain, continued for several years, would give a basis from which to draw conclusions.

Most volcanological studies have been made on isolated volcanoes or small groups of volcanoes, but usually only the major manifestations

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have been thought worthy of investigation and record. There are some problems, such as those mentioned, which can be much better attacked by studying the relations that different parts of a long chain bear to each other.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

Discussion

Following the two papers by Messrs. Sargent and Fenner, there was discussion by Dr. Wright and by the authors concerning the relative importance of explosion and subsidence in the production of the Alaskan craters. The evidence on the new craters described by Mr. Sargent is not yet sufficient for a final opinion. The outline of Aniakchak indicates an original cone 4,300 feet in height, and there is ash enough outside of the crater to restore such a cone. Dr. Fenner showed that the Katmai crater is due, at least in part, to subsidence. Dr. Washington cited Bolsena, Rocca Monfina, and other Italian examples of craters due to subsidence. Similar phenomena were mentioned by Brown and Washington for Kilauea, and Humphreys for Crater Lake. Messrs. Humphreys, Washington, and others also discussed the few existing data on sympathetic eruptions at far distant points.

THE NEED FOR SEISMOLOGIC OBSERVATORIES IN THE ALEUTIAN ISLANDS

FRANK NEUMANN

To the seismologist the idea of establishing a geophysical observatory in the Aleutian Islands immediately brings to mind two outstanding facts. First, it is the most neglected of any major seismic region of the world so far as securing local instrumental data is concerned; secondly, establishment of such an observatory would eliminate duplication of effort in the fields of instrumental seismology and volcanology. Just what the exact relation is between volcanoes and earthquakes, is immaterial at this time. It is sufficient to know that students in all branches of geophysics are unanimous in their support of observational projects which aim to explain this relation on a quantitative or correlative basis rather than on any other.

We are to discuss one phase of what is perhaps the most oustanding need of scientists who are studying volcanic and seismic activity in the Pacific. The Aleutian Islands region is famous for its volcanoes, its disappearing islands, and its mighty submarine earthquakes; yet, so far as scientific observation of these activities is concerned, it is practically

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a virgin field. In all the world of seismology it is the classic example of neglect.

Just how do the Aleutians fit in with other seismic regions of the earth? The earthquake regions of the Pacific, when viewed on a chart, describe a great curve convex toward the north. When examined on a globe we find them to coincide closely with a great circle. These things are mentioned in order to picture the seismic regions of the Pacific as constituting a great belt of activity as distinguished from an irregular distribution. The East Indies will arbitrarily be considered part of another great seismic belt stretching westward to southern Europe. The Pacific belt may then be defined as one extending from the Philippines to the lower part of South America.

Inasmuch as we are interested in studying instrumental control in the Pacific belt, we shall divide it into four parts, approximately equal in extent. The northern limit of the Asiatic region will be the southern part of Sakhalin Island, where the most northern Japanese observatory is located, at Otomari. The second, or Aleutian region, stretches from Otomari to Sitka, Alaska. The chief characteristics of this region are great submarine plateaus beneath the Bering Sea and deep submarine troughs immediately south of the Aleutian Islands. The third region extends from Sitka to the south border of Mexico; and the fourth southward through Central and South America. Although of a very arbitrary nature, these boundaries adhere fairly closely to political boundaries and are easy to visualize because each is approximately 3,500 miles in length.

On the basis of epicenters published by the British Committee on Seismological Investigations, covering the period from 1913 to 1920, I have estimated the percentage of total seismic activity in each of the four regions as follows: Japanese region 43 per cent, Aleutian region 19 per cent, North American region 18 per cent, and South American region 20 per cent. The distribution of observatories, expressed in percentage of the total number, is, for the respective regions, 46 per cent, 1 per cent, 37 per cent, and 15 per cent. Dividing the figures representing earthquake distribution by those representing observatory distribution we get what might be termed the relative regional efficiency of our observational scheme in the Pacific, taking seismicity into account. These relative efficiencies are represented by the figures 107 for the Japanese region, 5 for the Aleutian region, 207 for the North American region, and 80 for the South American region. In other words, if we took one-half the seismologic stations in North America and distributed them over the Aleutian Islands, we would have a fairly uniform distribution of existing observatories. As it is, we have in the Aleutian region one observatory at each end and none between.

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In the deeps off the Aleutian Islands we find the origins of probably more world-shaking earthquakes than in any other part of the world. If we acknowledge that seismologic stations are necessary anywhere, we cannot but recognize the very urgent need for additional stations between Sitka and Sakhalin Island.

Perhaps the greatest benefit to be derived from seismologic observations in the Aleutian region would be greater accuracy in locating earthquake epicenters in this region. Just because a determination of epicenter is published as final, one not familiar with the process may feel that all is well, not knowing that there may be a probable error of as much as fifty miles in position of origin and 20 or more seconds in time of origin. These discrepancies are, of course, due to our limited knowledge of the velocity of earthquake waves, including variations in velocity over different paths on the Earth's surface.

The nearer an observatory is to an earthquake origin, the more right we have to give its data greater weight in the final analysis because the probable errors necessarily diminish. This is important to remember because, no matter how excellent a record is obtained at any observatory, it is, in a sense, wasted effort (so far as accumulating velocity data is concerned) if we cannot determine within reasonable limits the position of origin of the earthquake from some nearby observatory.

Probably no other part of the world exhibits such wide variations in the velocity of earthquake waves as the Pacific basin; and on the evidence now available, particularly data collected at the Honolulu observatory of the Coast and Geodetic Survey, some of the greatest variations exist beneath the deeps between Hawaii and the Aleutian Islands. We find variations from the so-called standard seismological table so great that I venture to predict that in twenty-five years every first-class seismologic observatory will compile its own tables with corrections for azimuth and distance. To one who is familiar with the problem of interpreting seismograms, this seems to be the only solution; and some solution must soon be arrived at if we are to plot accurately the origins of earthquakes from instrumental data. Considering these problems of the future, the need for local seismological records in the Aleutians becomes increasingly apparent.

Dropping the problem of measuring the velocity of earthquake waves over great distances, we come to another group comprising earthquakes occurring, roughly, within a 500-mile limit. It is from records obtained within this radius that we learn something of the depths of focus of earthquakes, and also of the depths of the outer layer of the earth's crust. I shall do nothing more than touch on some theories involved in these problems, and this only because it makes clear one salient point. I will show why earthquakes of high intensity within 500 miles of an

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observatory are necessary to make records sufficiently sharp to record all the phases peculiar to nearby earthquakes. Because of this requirement, a first-class observatory in the Aleutians is eminently desirable.

Imagine the focus of an earthquake to be 25 km. below the surface of the earth, and suppose the depth of the earth's outer layer to be 50 km. It is easy to picture how waves radiating from this focus can reach a nearby observatory over a straight path through the outer crust. Because of the curvature of the earth's crust, it is possible for the rays, or elements of a wave front, to reach a more distant observatory over two paths; one through the outer crust only; the other by passing downward through the outer layer into the layer beneath it and back again through the outer layer to the observatory. Thus the appearance of two phases of the same elementary wave front on a seismogram depends upon the distance of the observatory from the origin, the depth of focus, and the depth of the outer layer. Both of these phases are necessary for discussion of depth of focus and depth of layer, and they are not obtained unless the earthquakes recorded be within the 500-mile limit, for beyond this distance all of the recorded waves penetrate the layers below the outer one.

Another method of measuring the depth of focus and the thickness of the outer layer depends upon recording at nearby observatories waves which have been reflected from the bottom of the outer layer, or which have suffered several reflections between the bottom of the outer layer and the surface. Very promising results have been obtained in studies of strong local shocks in Porto Rico. Investigations of this kind could be carried on to still greater advantage in the Aleutians.

American geophysical institutions should consider it a privilege to support any project looking toward the establishment of a geophysical observatory in the isolated Aleutians, contributing, if necessary and practicable, personnel, instruments, and funds. If they are to profit by the operation of such an observatory, they should also assist in its establishment and maintenance.

U. S. Coast and Geodetic Survey.
Washington, D. C.

Discussion

Dr. Humphreys remarked on the number of seismologic stations listed in the United States, and the number that are really active. Prof. Brown inquired concerning the possibility of a seismograph which would record for several months on an isolated island, without attention. The speaker said that no such instrument is now available, as the need for accurate time-records makes very long graphs necessary. Simple records of intensity, without accurate records of time, would be useful, however.

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PROBLEMS IN TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY PERTAINING TO THE ALEUTIAN ISLANDS

J. P. AULT

Prior to 1915, magnetic observations in the Aleutian Islands were limited to 30 values at eight localities on land and 14 values at 10 localities at sea, the first observations having been made at Dutch Harbor in 1867. In 1915, the *Carnegie* made observations in the vicinity of the Aleutian Islands during her cruise up into the Bering Sea, calling at Dutch Harbor on the way north, and returning south near Attu, the westernmost island of the group. During the following year, on the same cruise, she passed near the group on her voyage across the north Pacific from Guam to San Francisco. In 1925 Lieut. G. C. Jones of the Coast and Geodetic Survey made observations at four islands of the group, establishing 12 stations, his results indicating very large local disturbances, especially on Atka Island. Three of these islands had been occupied in 1873, and the results of Lieut. Jones' observations give valuable information concerning the annual variation at the repeat stations.

Thus we see that up to the present time the magnetic data in and around the Aleutian Islands depend upon one land expedition and one sea voyage, supplemented by earlier observations scattered in distribution as to time and locality and of uncertain value, owing to the presence of local disturbances. This scarcity of observations in the Aleutian Islands has been due chiefly to inaccessibility and lack of transportation facilities. Any assumption of annual-change values in the group is based on insufficient data except at Dutch Harbor, where observations have been repeated at frequent intervals since 1867.

Owing to the presence of pronounced local disturbances due to the volcanic nature of the islands, secular changes probably will be irregular, and values of these changes as determined ashore may not be assumed to hold for localities at sea and vice versa. Investigations by H. W. Fisk at Bermuda indicate that the secular change is considerably modified in regions of local disturbance. Observations by the Carnegie Institution of Washington among the islands of the South Pacific Ocean point to the same conclusion. The Aleutian Islands will be a fruitful field for an investigation of this effect, since the normal annual change can be controlled by repeated observations at undisturbed localities on the ocean in the vicinity of shore stations which are locally disturbed. Thus there is need for repeat observations, not only on land but also at sea, throughout the extent of the Aleutian Island chain.

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For the purpose of improving the conditions of navigation, both at sea and in the air, regions of local disturbance in the islands should be investigated in detail to determine their extent and amount. This group of islands very probably in the near future will form the highway over which air travel will pass between North America and Asia. The planes of the Army Air Service followed the Aleutian Islands on their flight around the world. Since these planes were equipped with the new earth-inductor compasses a knowledge of the inclination as well as of the declination was of great value. On account of the possibilities of future travel by air the distribution and variation with time of the magnetic elements in this group of islands should be thoroughly known.

To quote from recent reports of the Director of the Coast and Geodetic Survey: "There is great need for a magnetic survey of Alaska, especially in the interior and along the Aleutian Islands. Magnetic maps of Alaska are based on insufficient data and the results at the Sitka Magnetic Observatory, while invaluable, do not give the changes for the entire region. . . . Magnetic data for Alaska are nowhere more than barely sufficient, and in many cases entirely insufficient for placing correct magnetic information on the mariner's charts." This condition was somewhat bettered as regards the Aleutian Islands by the work of Lieut. Jones in 1925, but the work should be extended, should be repeated at an early date, and should be more detailed in regions of local disturbance.

The study of the electricity of the air is increasing in importance owing to its close connection with terrestrial magnetism and to its association with the problem of radio transmission. New additions are constantly being made to our knowledge of correlations between changes in solar activity and variations in the phenomena of atmospheric electricity. The need for additional observations of the electricity of the air cannot be overemphasized, especially in regions similar to the Aleutian Islands, in high latitudes and remote from continental land masses.

So far, no atmospheric-electric observations have been made in the Aleutian Islands except the observations made at sea on the *Carnegie* during the 1915-1916 cruise already mentioned, together with two diurnal-variation series of potential-gradient, ionic-content, and penetrating-radiation observations during her stay in Dutch Harbor. The first of these series was interrupted by fog and mist after eight hours of observations, but the second series was continued for 24 hours and the results agreed well with a 24-hour series taken two weeks later in the Bering Sea. For the potential gradient, the chief component apparently was a 'wave" of 24-hour period, the maximum value coming at about 23^h G. M. T. both at Dutch Harbor and in the Bering Sea. The results at Dutch Harbor were more scattered and of greater range than in the

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Bering Sea, possibly owing to the influence of land and of nearby mountains, with rapidly changing conditions of weather. These observations should be repeated at other points in the Aleutian Islands to see if the maximum value occurs nearer the G. M. T. of 17^h to 19^h as determined by Mauchly from a discussion of all the results of ocean observations on the *Carnegie,* and to add confirmation to Mauchly's deduction that this 24-hour wave progresses approximately according to universal time over the entire land surface of the earth.

While the meteorological conditions in the group are not of the best, yet an atmospheric-electric observatory could be operated on some island in the center of the chain and would give results of unique value and importance owing to the absence of smoke and dust disturbances usually found near other atmospheric-electric observatories located near large centers of population. The conditions would be practically the same as exist at sea, due to the distance from large continental areas, and experience has shown that ocean observations have been far less disturbed than land observations.

Only one atmospheric-electric observatory is in operation in the Pacific Ocean, that at Apia, Samoa. An observatory at the Aleutian Islands would supplement greatly the one at Apia in its contributions toward a solution of the many problems of atmospheric electricity in the study of the variations with latitude and with the seasons, of the daily and annual changes, and of the effect of climatic and meteorological changes.

To emphasize the scarcity of magnetic and electric data in these regions, and the urgency of increasing our knowledge of the magnetic and electric conditions in the far north, the following resolutions were adopted at the Madrid meeting of the International Section of Terrestrial Magnetism and Electricity, October, 1924:

> "That the Section deems it highly desirable to call attention to the need of additional magnetic and electric observations in high latitudes, especially north of 60° N. and south of 50° S.
>
> "The section calls attention to the need of additional field observations and observatories pertaining to terrestrial electricity.
>
> "The section recommends the desirability of obtaining magnetic data from high latitudes in years near sun-spot maximum to supplement those near sun-spot minimum already obtained to some extent by certain Antarctic expeditions and that this matter be brought to the attention of future expeditions."

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METEOROLOGICAL OBSERVATIONS IN THE ALEUTIAN ISLANDS

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Abstract.—The maintenance of regular observing stations in the Aleutian Islands and of uninterrupted communication between them and the Pacific coast of the United States is of very great importance to the Weather Bureau. The U. S. Navy maintains radio stations at Dutch Harbor, Kodiak, and St. Paul, and twice-daily observations are sent from each of these stations.

The importance of meteorological reports from the Aleutian region, as well as from the mainland of Alaska, has long been recognized. It has been thought generally by meteorologists in the past that the Gulf of Alaska is the breeding place of the storms that enter British Columbia from the Pacific Ocean, because of the more or less permanent area of low pressure over that region much of the year and because of the great difference in temperature, especially in the colder months, between that area and the interior of Alaska—a condition favorable to storm development. In recent years, however, the charting of meteorological reports from Japan, the Philippine Islands, the coast of China, and from a constantly increasing number of vessels that report daily by wireless while crossing the Pacific Ocean, has furnished much material for study of the storms of the North Pacific Ocean, and it has been found that all, or nearly all, of the storms that enter British Columbia or our north Pacific coast originate far beyond the Aleutian Islands. Many of them move northeastward over or near Japan and pass near, or south of, Dutch Harbor into the Gulf of Alaska, the so-called permanent area of low pressure simply affording a channel through which the disturbances pass, rather than being their breeding place. Hence the receipt of meteorological reports from the Aleutian Islands is essential in order to have advance information of the approach of the numerous storms that cross the North Pacific Ocean. At present, Dutch Harbor is the meteorological outpost in the Aleutians; but there is great need for an observing station at Attu, the most westerly of the Aleutians, in order to fill in the gap between Dutch Harbor and Japan. The establishment of means of communication with this island remains a problem for the future.

U. S. Weather Bureau,
Washington, D. C.

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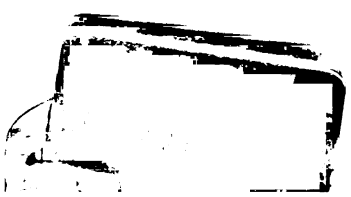

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